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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXLIX.

EDITED BY

J. H. T. TUDSBERY, D.Sc., M. INST. C.E., SECRETARY.

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CORRIGENDA.

Vol. cxlii. p. 146, line 12, *for* "Total weight" *read* "Weight of each."
,, cxlvii. p. 182, *for* "L_a = load on axle," etc., *read* "L_a = load on axles," etc.
,, cxlix. p. 153, line 22, *for* "live" *read* "line."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1901-1902.—PART III.

SECT. I.—MINUTES OF PROCEEDINGS.

11 February, 1902.

CHARLES HAWKSLEY, President, in the Chair.

(*Paper No. 3278.*)

"The Port of Dundee."

By GEORGE CUNNINGHAM BUCHANAN, M. Inst. C.E.

IN 1895 the late Mr. David Cunningham, M. Inst. C.E., contributed to the Institution a Paper[1] on "The Estuary of the Tay," in which the general physical conditions of the Firth were fully described. In this Paper the Author proposes to deal with the harbour and docks of Dundee, and the effects of the harbour and railway works on the sandbanks in their vicinity.

THE HARBOUR AND DOCKS.

Historical.—Dundee, situated on the north bank of the Firth of Tay, 9 miles from its mouth, is the third town and port in Scotland, and the centre of the jute and linen industries. The harbour is managed by a public trust, under various Acts of Parliament consolidated in the Act entitled "The Dundee Harbour Consolidation Act 1875." The jurisdiction of the Harbour Trustees extends from the Bar of Tay on the east to Balmerino on the west, a distance of 17 miles, and on them devolves the maintenance of the navigation-channel, including the upkeep of the lightship, lighthouses, buoys and beacons, the fishery harbour at Broughty Ferry, and the docks and wharves at Dundee. They also own the Tay Steam Cart Ferries, which ply between Dundee and Newport. Owing to the exposed position of the port in the estuary, harbour protection-works were essential from the earliest times when ships frequented it. The first mention of built structures in the local records is in 1447, and in 1770 Smeaton executed considerable repairs and extensions to the works. In 1812, when a connected history of the harbour may

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[1] Minutes of Proceedings Inst. C.E., vol. cxx. p. 299.

be said to begin, the accommodation consisted of a tidal basin about 4½ acres in extent, with protecting piers on the east and west, and two insulated breakwaters on the south or sea side, forming one principal and two narrow entrances. There was also a scouring-basin, ⅓ acre in area, the walls of which were just below high-water level of neap tides, and at low water, on sluice-valves being opened, the basin and entrance were partially cleansed of mud.[1]

Building of the West Docks.—In 1815 a want of dock accommodation began to be felt, and Thomas Telford designed a new and comprehensive dock system, comprising a tidal basin, wet dock, and graving-dock. Dundee being partly situated on a narrow strip of flat ground extending from the river-bank to steep rising ground on the north, docks were only practicable by reclaiming from the river, and all subsequent harbour-extensions have been carried out on similar lines. These works were completed in 1825 at a cost of £90,000 (Fig. 1, Plate 1). The wet dock encloses a water-area of 6¼ acres, and has 2,430 lineal feet of quayage, and a lockway 39 feet in width by 170 feet in length. The dry dock is 278 feet in length, with similar breadth of entrance, and although now only used for the smallest class of vessels, was at the date of construction found fault with on account of its large size, and was described by Telford as not inferior in excellence to any in the kingdom. The walls of both wet and dry docks were constructed of masonry from local sandstone-quarries.

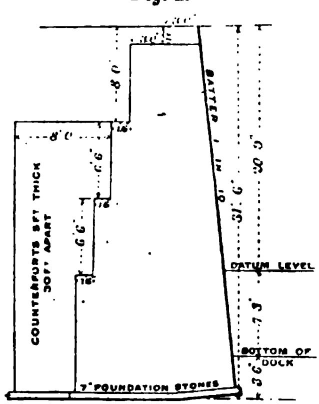
The result of a progressive policy soon became apparent, as the tonnage of ships visiting the port increased from 70,000 tons in 1815 to 165,000 tons in 1829, and the revenue from £1,700 in 1814 to £11,000 in 1829. In 1830 it became evident that dock-extensions were essential to the welfare of the town, and between that date and 1848 the tidal harbour was converted into the Earl Grey Dock, having an area of 5 acres, 2,240 feet of quayage, and an entrance lock 55 feet in width by 215 feet in length, with a depth of water of 17 feet 6 inches at high water of spring tides. The gates had cast-iron heel- and mitre-posts and cast-iron ribs, planked on both sides with Memel fir, and cost £2,795; the masonry and excavation of the lock costing £9,000, and the whole work £46,000. A slip was also provided, the marine parade was extended, and the east tidal harbour was built (Fig. 2, Plate 1).

Construction of East Docks.—In 1855 the average draught of the larger vessels frequenting the port was between 16 feet and 17 feet, and as on a neap tide the depth of water on the sill of the Earl

[1] According to Mr. Cunningham's Paper, the range of ordinary spring tide at Dundee is 16½ feet.—SEC. INST. C.E.

Grey Dock was only 14 feet 6 inches, they were obliged to load or discharge a large part of their cargoes in the river by lighters, at great additional cost and inconvenience. The revenue of the harbour had increased from £16,810 in 1840 to £23,361 in 1854. The first importation of jute in any quantity occurred about 1835, and although up to 1840 the manufacturers had obtained their supplies from the London and Liverpool markets, a direct trade with Calcutta was being established, and the importation at the harbour had increased from 1,948 tons in 1842 to 9,048 tons in 1855. Many proposals for additional accommodation were formulated, and finally an Act of Parliament was obtained to convert the east tidal harbour into the Camperdown Dock. This work was commenced in 1857, but the collapse of the whole of the east wall of the dock and a lengthy lawsuit with the contractors delayed its completion until the year 1865, when the dock was opened to traffic, having cost £100,000 to build. The dock has an area of 8½ acres, with 2,400 lineal feet of quayage, and an entrance 60 feet wide, with a depth of 21 feet 8 inches of water on the sill at high water of spring tides, and closed by a hinged caisson (Fig. 5, Plate 1).

Fig. 4.



Scale, 1 inch = 16 feet.

CROSS SECTION OF VICTORIA DOCK WALL.

The Victoria Dock and the East Graving-Dock were next constructed, in 1871–1876. The Victoria Dock has an area of 10¾ acres, 3,014 feet of quayage, and a depth of water of 21 feet at high water, *Fig. 4.* The East Graving-Dock is 500 feet long, with a width of entrance of 53 feet, and a depth on the sill of 18 feet 6 inches at high water. The walls of the graving-dock are built of rubble sandstone masonry, founded on a bed of flat stones. The outer faces are of hammer-dressed rubble, with ashlar courses at the sides of the floor, and on the altars, copings, timber slides, caisson platform, inverts, stairs, etc. The floor is 8 feet 4 inches in thickness at the centre, has an inverted arch of rubble on a foundation bed of Portland-cement concrete, and is paved with rubble blocks on the surface, Fig. 6, Plate 1. The dock is closed by a caisson 7 feet in breadth and 25 feet 3 inches in height, the lower part of which is divided by five watertight plate floors

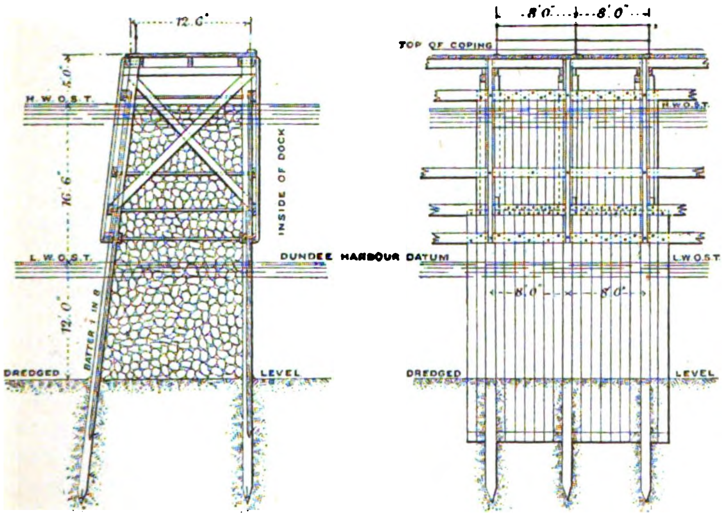
into four sets of chambers, and the caisson is provided at one end with hinges, and at the other with a vertical pneumatic chamber. There are also five sluices, each measuring 2 feet 9 inches by 2 feet, through which water is admitted into the dock, Figs. 7, Plate 1. The Victoria Dock cost £98,000, and the Graving-Dock £60,645.

Deep-Water River-Wharves.—In 1891 the question of harbour-extension was again brought forward, by a report from the harbourmaster drawing attention to the serious detention of large steamers, owing to the fact that with few exceptions all vessels drew 23 feet of water, and had to be lightened in the river before entering the docks. From want of foresight on the part of the Harbour Board of that date, the only piece of ground available for dock extension eastward had been let to a shipbuilding firm; and a proposal to extend into the river and build a dock embracing the Beacon Rocks was negatived on the score of expense. It was finally decided to build river-wharves, and to erect sheds east of the shipbuilding-yards, abandoning the use of the docks for large vessels. The construction of 2,800 lineal feet of river-wharf, with 24,650 square yards of shed, has enabled the largest steamers to lie and discharge at any time of the tide without inconvenience. The timber wharf being of a temporary nature, and more shed-accommodation being required, the construction of a permanent river-wall, 140 feet outside the present wharf, is about to be commenced. The new wall will be 2,000 feet in length, with a dredged depth alongside of 27 feet at low water of ordinary spring tides, and an additional row of sheds will be built outside those at present in use, Fig. 3, Plate 1.

Tidal Dock for Steam Trawlers.—In 1898 it was found necessary to provide special accommodation for the steam trawlers fishing from the port, Parliament having decreed that until this was done dues could not be levied. The modern steam trawler, a vessel of 120 feet to 150 feet in length, 20 feet to 25 feet in beam, and drawing up to 14 feet of water aft, has revolutionised the fishing-industry; and as quick despatch and a dock that can be entered at any state of the tide are essential to success, the small shallow harbours which abound on the coast have been rendered in a large measure useless, and a concentration of the trade has taken place at various centres. In Dundee there was no suitable accommodation, the West Docks being deficient in depth, and it was impossible, except at a prohibitive cost, to remedy this defect. The river-wharves had abundance of water alongside, but no protection for small steamers from the gales that sweep down the estuary. The Author was of opinion that the most suitable site would be at the extreme east end of the harbour, where there was a large piece of

vacant ground available for fish-curing purposes; and he designed a tidal dock having 8 acres of water-space, 2,743 lineal feet of quay, and 6,700 square yards of market, with a depth of water in the entrance-channel of 12 feet 6 inches at low water of ordinary spring tides. The first section was opened in June, 1900. To give protection from westerly gales, a breakwater was run out to the point where the new deep-water quay will commence, and the body of the dock was formed by excavating a portion of the ground reclaimed from the river in former years. The breakwater consists of two rows of whole-timber pitch-pine main piles 8 feet

Figs. 8.



Scale, 1 inch = 20 feet.

BREAKWATER OF NEW TIDAL BASIN FOR TRAWLERS.

apart from centre to centre, and half-timber sheeting, the space between the two rows being filled with rubble, *Figs. 8.*

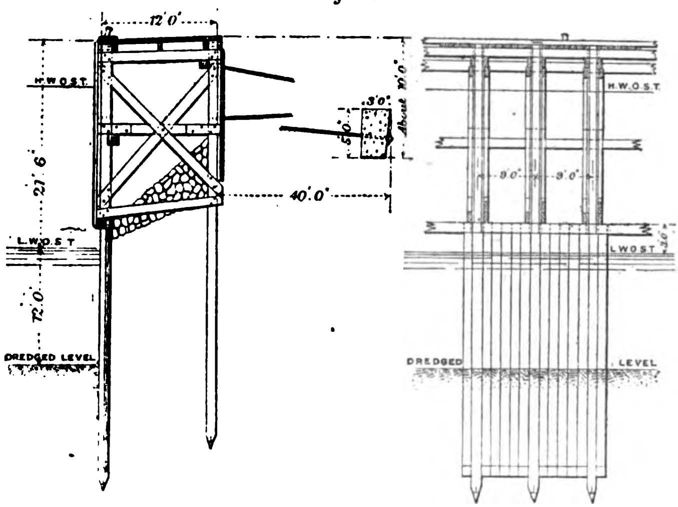
The landing-wharf is 12 feet 6 inches in width, is constructed of two rows of main piles, 9 feet apart from centre to centre, with sheeting between the piles of the first row, and is tied by iron tie-rods, $1\frac{3}{4}$ inch in diameter, and 50 feet in length, *Figs. 9.* There are bollards along the face of the wharf, 18 feet apart, and numerous ladders down to low-water level.

The market is 50 feet in width, with wooden framed ends, and a row of cast-iron columns at back and front supporting the girders which carry the steel principals of the roof. In lieu of sliding

doors, which take up a great deal of room, the Author adopted wooden roller-shutters, 16 feet in width, and 11 feet in height (Figs. 10, 11, 12, Plate 1). These were made in the harbour workshops of pitch-pine laths threaded on steel wire and fastened to an iron drum, 1 foot in diameter. By means of balance-weights and a simple gearing, one man can with ease lift and lower the shutters.

The works were carried out departmentally. The breakwater cost £11 per lineal foot, and the landing-wharf £9 2*s.* 6*d.* per lineal foot, or 14*s.* 5*d.* per square foot of quay. The cost of pile-

Figs. 9.



Scale, 1 inch = 20 feet.

North Wharf of New Tidal Basin for Trawlers.

driving throughout averaged 2*s.* 3*d.* per cubic foot, being 1*s.* 8½*d.* for timber and 6½*d.* for labour; whilst that of the other timber work averaged 3*s.* per cubic foot, viz., 1*s.* 9*d.* for material and 1*s.* 3*d.* for labour. To these amounts ironwork added 5*d.* per cubic foot of timber used. The market cost complete 4*s.* 11*d.* per square foot of flooring, the rolling shutters costing 3*s.* per square foot of opening.

Equipment and Working of Harbour.

Apart from a general coasting and continental trade and a large timber importation, Dundee depends almost entirely on the Indian jute-industry for its support, and special facilities and equipment

are provided for this particular trade. On an average one million bales, or 180,000 tons, of raw jute are imported from Calcutta annually, the greater part of which arrives at the port between the months of October and April in cargoes ranging between 20,000 bales and 50,000 bales, each bale measuring 4 feet by 1 foot 6 inches by 1 foot 9 inches, and weighing 400 lbs.

Transit-Sheds.—Around the docks and river-quays there are single-storey transit-sheds covering an area of 45,000 square yards. A cross section of one recently erected by the Author is shown in Fig. 13, Plate 1. It is 300 feet in length by 120 feet in breadth, in two roof-spans of 60 feet, and the height from ground-level to the eaves is 13 feet 9 inches. The walls are of brick, with ashlar quoins and tabling, and there is a row of cast-iron columns along the centre of the shed supporting the roof, and a similar row on the river-front, which is closed in with wooden sliding doors. The roof covering is of slate, and the principals and girders are of mild steel. The shed is floored with granolithic pavement consisting of a 4-inch layer of broken stone, upon which is laid 4 inches of Portland-cement concrete, covered with 2 inches of granolithic, composed of clean granite chips and Portland cement, gauged 1 to 1. The cost is *5s.* per square yard, and this flooring is found very satisfactory for both light and heavy traffic. The total cost of the buildings averages *3s.* per square foot of ground covered.

Iron Storage-Warehouses.—In the jute-season considerable difficulty is experienced in getting the transit-sheds cleared, owing to the cargo being discharged from the steamer much more rapidly than it can be carted to the mills and town warehouses. This is specially the case at the east wharf, where, on account of the lack of depth in the docks, the majority of the Indian liners are berthed; and at the Author's suggestion a row of storage-warehouses has been built immediately opposite the transit-sheds, by which means the congestion of the traffic has been considerably abated. They are single-storey warehouses, constructed of iron with party-walls of rubble-masonry, and cost 0·97*d.* per cubic foot of contents, or *2s.* per square foot of ground covered.

Warehouse for General Merchandise.—In addition to the sheds, there is a five-floor warehouse at Victoria Dock, with a capacity of 270,000 cubic feet, which cost £16,147 to build.

Hydraulic Machinery.—Up to the year 1882, jute-cargoes were discharged by means of small steam-engines placed on the quay, but the danger from fire, owing to the inflammable nature of the jute, and the damage to goods and sheds from smoke and dirt was so considerable that a small installation of hydraulic machinery

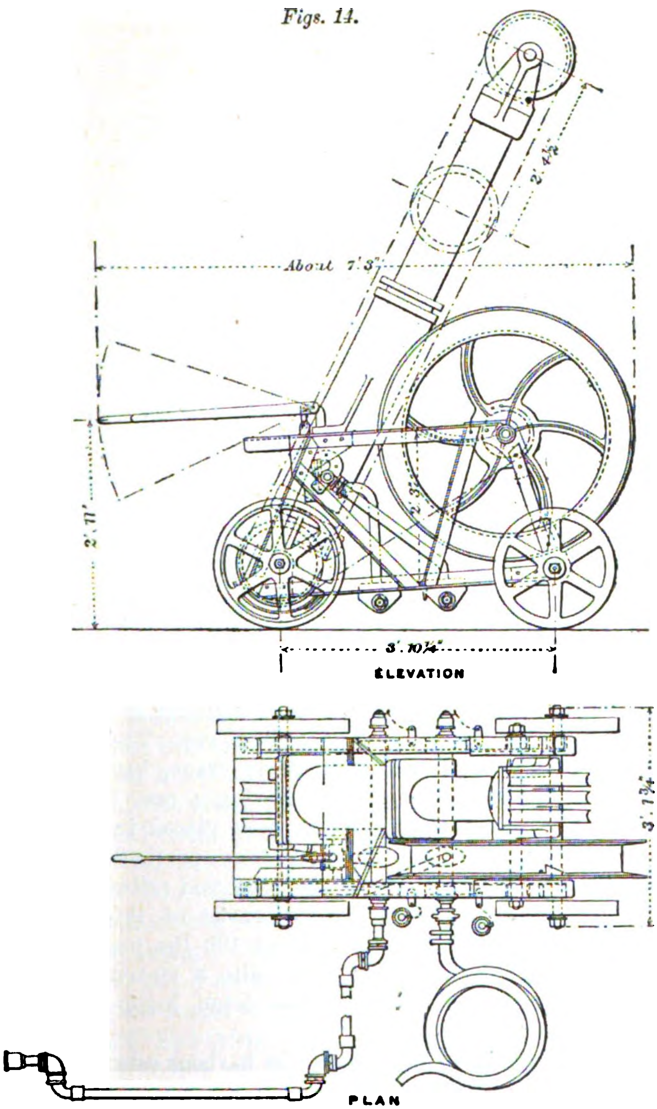
was put down, which has been since extended. The harbour is now almost entirely worked by hydraulic machinery, and the present plant consists of a central station containing one compound non-condensing pumping-engine, made by Messrs. Sir W. G. Armstrong and Company, having cylinders 10½ inches and 15½ inches in diameter by 15 inches stroke; one compound horizontal surface-condensing pumping-engine made by Messrs. Tannett Walker and Company, having cylinders 14 inches and 24 inches in diameter by 21 inches stroke; one compound surface-condensing steam pumping-engine capable of discharging 160 gallons of water per minute at the accumulator pressure of 700 lbs. per square inch, supplied in 1897 by Messrs. Sir W. G. Armstrong and Company; one Lancashire boiler, 6 feet in diameter, 18 feet in length, working-pressure 100 lbs. per square inch; one internally-fired multitubular boiler, 6 feet in diameter, 16 feet 6 inches in length, working-pressure 95 lbs. per square inch; one internally-fired multitubular boiler, 5 feet in diameter, 11 feet 6 inches in length, working-pressure 80 lbs. per square inch.

There are two accumulators at the central station with 10-inch and 12-inch rams respectively, and 12 feet stroke, and an auxiliary accumulator at the east wharf with a ram 10 inches in diameter and 12 feet stroke. The main pressure-pipes are 3 inches and 4 inches in internal diameter, and the working-pressure is 700 lbs. per square inch.

The machines used are 5-cwt. movable jigger-hoists supplied by Messrs. Sir W. G. Armstrong and Company, and there are now thirty-two of these in operation, *Figs. 14.* They have rams 7¼ inches in diameter with 2 feet 2 inches stroke, and by means of multiplying sheaves and drums can lift the load of 5 cwt. through a height of 50 feet at the rate of 12 feet per second. The pressure pipes are laid underneath the deck-planking of the wharf, and have numerous jigger-connections conveniently placed. A stage on trestles runs from the wharf to the steamer's hatchway; the bales are hoisted up one by one at the end of a hemp rope passing from the jigger-drum over a pulley on the ship's derrick, and are received by a man and pulled to the stage; they are then slid to the wharf, where they are wheeled to the transit-sheds, weighed and loaded on to lorries by the harbour-porters. A jigger can make five lifts per minute, so that a steamer with five hatchways and a jigger at each, can, theoretically, be discharged at the rate of twenty-five bales, or 5 tons per minute. Unfortunately this rate is never continuous for any length of time,

as numerous stoppages occur, both to break out the cargo and on

Figs. 14.



Scale, ⅜ inch = 1 foot.

Movable Jigger-Hoist.

account of congestion in the transit-sheds; but a steamer with a

cargo of 33,000 thousand bales has been cleared in 59 hours from the time of berthing. The average discharge, however, is about 4,500 bales per working-day.

The total cost per ton for discharging and loading on to lorries is *4d.* from ship to quay, and *6d.* to *8d.* from quay to lorry, the latter charge including depositing in shed, selecting, weighing and loading. Besides hydraulic jiggers there are, worked by hydraulic machinery, a 20-ton crane, warehouse hoists, capstans, etc.

A hydraulic coal-hoist, adapted to lift a wagon of 20 tons through a height of 50 feet above the level of the jetty, and to tip it, when raised to that height, through an angle of 45°, is in course of erection (Figs. 15, Plate 2). Owing to the difficulty in providing suitable foundations at a moderate cost, the hoist having to stand in the river 120 feet out from the line of the existing quay, the Author decided to adopt the suspended hoist of Messrs. Sir W. G. Armstrong, Whitworth and Company instead of that in which the cradle is lifted by direct-acting cylinders placed in a well below the surface of the quay. A substantial timber jetty was accordingly built, on which the hoist is being erected. The hoist-framing is of steel, braced and strutted, and securely bolted to the timber-work of the jetty. The cradle and tipping-frame are lifted and lowered by four chains, two for lifting and two for tipping; the lifting-cylinder is fixed vertically against one side of the framing, the tipping-cylinder is fixed on the upper end of the lifting-cylinder, and each cylinder is fitted with a plunger, multiplying sheaves, guide-bars, etc. The hoist is also furnished with a 2½-ton anti-breakage crane, having a lift of 55 feet; an auxiliary accumulator, having a ram 1 foot 8 inches in diameter and 35 feet stroke, has been placed in the vicinity. The hoist is the largest built of that particular type, and will cost, complete with foundations, jetty and railways, £12,500.

The fire-extinguishing appliances consist of thirty-seven box hydrants, with an effective pressure of 100 lbs. per square inch, and a steam fire-engine. There are also a 90-ton steam-crane, a 30-ton steam-crane and numerous 5-ton hand-cranes placed round the docks.

There are 8½ miles of railway on the harbour estate with which both the North British and Caledonian Railway Companies have connection. The Dundee and Perth line was made in 1846, and the North British main line to Aberdeen, viâ the Tay Bridge, passes under Dock Street by means of a tunnel, and was built in 1878.

Movements of Sandbanks in the Vicinity of the Harbour.

The estuary of the Tay is of the narrow-necked type, and at Broughty Ferry, which is the narrowest part of the neck and 7¾ nautical miles from the bar, the width is ¾ mile, and the depth at low water of spring tides 60 feet. The Port of Dundee is situated on the north bank, 3 miles above Broughty Ferry, and the width there is 1¼ mile, widening uniformly to 2¾ miles at a distance of 4 miles farther up, whence it decreases to ¼ mile at the mouth of the River Earn, 24 nautical miles from the bar. Over the upper part of the estuary, sandbanks extend over many square miles, mainly on the north side, and the Author proposes to trace the movements and changes in the banks in the immediate neighbourhood of the harbour as shown in Figs. 16, Plate 2.

In the year 1816, which is the date of the first reliable chart, the Middle Bank had an area of 140 acres above low water of spring tides, and an average height of 8 feet above the same level. Its formation was probably due to a reduction in the average speed of the tidal currents in that portion of the estuary in which the bank was situated, owing to the greater breadth of that portion as compared with the portion below, and to the fact that although the body of the tide ebbed on the south side, there was a strong set of the flood-tide on the north side, the bank lying between the two. The main channel of the Tay opposite the harbour was then, as now, on the south side, but there was on the Dundee side a subsidiary channel to the north of the Beacon Rocks, and thence into Queens Roads, and between the latter and the south channel lay the Middle Bank. The ballast-bank lay on the north side of the river, stretching east from Magdalen Point, and was a natural result of the configuration of the coast.

The state of the sandbanks in 1833 showed but little change since 1816. In 1870 the ballast-bank had moved down, and was blocking the entrance to the harbour, the portion above low water of spring tides being 2 feet in height. The Middle Bank had travelled north and become reduced in size from 140 acres to 20 acres above low water of spring tides.

Between 1835 and 1842 the Perth Harbour Commissioners, acting on the advice of Messrs. Stevenson, had carried out improvement-works in the upper portion of the river, involving the removal of 841,480 tons of material from its bed, thus equalizing the depths in the shallows to 5 feet at low water and 15 feet at high water of spring tides. These works depressed the low-water level at Perth by 2 feet, and increased the velocity of

the tidal wave between Newburgh and Perth by $1\frac{2}{3}$ mile per hour. The harbour-works at Dundee were begun in 1816, and between that date and 1869, 135 acres of ground were reclaimed from the foreshore of the river, the total amount of reclamation up to the present date being 328 acres.

Diverse opinions have been expressed by engineers as to the cause of the change in the banks opposite Dundee, some attributing it to the excavations in the upper part of the river. The Author considers the movement of the ballast-bank undoubtedly due, first, to the construction of the Dundee and Perth railway embankment in 1845, and secondly, to the building of the Dundee esplanade in 1869, as the speed of the tidal currents outside the straight line of wall must have been increased, and the sand immediately in front been carried down stream and deposited in front of the harbour. The decrease in the size of the Middle Bank was a natural result of narrowing the estuary by the projection of the docks and esplanade into the river, and thus increasing the velocity of the tidal currents in the main channel. In 1870 dredging-operations were commenced on the bank in front of the harbour, and between then and 1879, 500,000 tons were removed, and the whole of the river-bed formerly occupied by the bank was deepened to 6 feet below low water of spring tides.

Railway Bridges over the Tay at Dundee.—The construction of the first Tay Bridge was commenced in 1871 and was completed in 1878, and in view of the effect of these works on the harbour-approaches, the Author presents the following brief description of their construction :—

On the north side the bridge consisted of 25 spans of 67 feet each, on a curve of 20 chains radius, 11 spans of 130 feet, and one span of 162 feet. Then came the navigation-spans, 11 spans of 245 feet, and 2 spans of 227 feet. The piers were formed of iron cylinders filled in with brick and cement, were carried up to 5 feet above high-water level, and measured in the large spans 28 feet in length and 16 feet in breadth, the small spans being 12 feet 6 inches in length and 11 feet in breadth. The first bridge fell in the gale of the 28th December, 1879, and the second bridge was commenced in 1882 and completed in 1887. The centre-line of the new bridge was laid out 60 feet west of the old piers, but the number and length of the spans remained the same. Each pier was formed of two wrought-iron cylinders filled with concrete and brickwork, and sunk into the river-bed. The cylinders of the narrow spans were 9 feet in diameter up to high-water level, and 17 feet apart, the cylinders of the 130-foot spans were 10 feet

6 inches in diameter at high-water level, and 15 feet 6 inches apart, and the cylinders for the navigation-spans were 14 feet 6 inches in diameter between low-water and high-water levels.

Between the year 1871, when the first bridge was commenced, and the year 1879, when it fell, the bed of the river between the navigation-spans was lowered an average of 5·41 feet by scouring action, and from observations made by the Author in 1898, it was ascertained that, since the erection of the new bridge, the bed of the river in the navigation-spans had been lowered an additional 3·39 feet, or 8·80 feet in all. In 1879 the Middle Bank was entirely gone, and on its former site was 15 feet to 17 feet of water at low water of spring tides (Figs. 16, Plate 2). A new Middle Bank, having an area of some 67 acres above low-water level had, however, appeared about 2,500 feet from the north shore, stretching from the Tay Bridge eastward. In 1885, although the area above low-water level had decreased, the depth of the river-bed below low-water of spring tides in front of the esplanade had diminished, and from that date up to 1893 the area of the bank above low water increased steadily year by year, and the buoy marking the passage for the ferry-steamers at the tail of the bank was moved in a north-easterly direction 1,700 feet altogether. Since 1893 there has been no change in the position of the buoy, and it is not apprehended that there will be any further downward movement, as, owing to the gradual narrowing of the estuary, the speed of the tidal currents becomes too great to allow sand to lie farther down the stream. The lower end, although not permanently extending, is constantly changing. A prolonged drought and high spring tides have the effect of diminishing the bank, whilst the effect of land-floods and neap tides is to cause it to increase.

In 1888 the Dundee Corporation commenced an extension of their esplanade westward, which was completed in 1893. The wall was built on a sandbank, and the immediate effect was to scour in the neighbourhood of the elbow 150,000 tons of sand, which was deposited below the bridge and formed another bank between the new Middle Bank and the shore. The Corporation have now obtained powers to reclaim an additional 132 acres of foreshore, and to construct an extended esplanade 7,000 feet in length. The material on which it is proposed to build this wall consists, for a depth of 16 feet, or 14 feet below low water of spring tides, of soft fine sand and mud, and it seems probable that a vast amount will be scoured and deposited in the vicinity of the harbour. The superior force of the ebb-tide will then in due

course carry it in front of the docks, blocking the entrances, as was the case in 1869. From a series of cross sections of the river taken at different periods (Figs. 17, Plate 2), the Author has computed that between the years 1879 and 1900, 2,639,000 cubic yards of material have been deposited over the area between the esplanade on the north, the south side of the new Middle Bank on the south, the Tay Bridge on the west, and the Craig Pier on the east.

Reasons for the Shoaling of the River-bed.—The serious shoaling of the bed of the estuary which is so prejudicial to the interests of the harbour, and especially to the Tay Ferries Navigation, is, in the opinion of the Author, almost entirely due to the obstruction of the tidal currents caused by the piers of the Tay Bridge (Fig. 18, Plate 2) which, from pier No. 41 to pier No. 78, a length of 3,350 feet on the north side of the estuary, have, owing to the plan on which the bridge has been constructed, diminished the speed of the tidal currents to an extent sufficient to allow the sand brought down by the river to be deposited over the area referred to; and whereas the main channel through the navigation-spans has been deepened, and the speed of the currents increased, a sand-trap has been formed in the slack water on the north side between the bridge and the Craig Pier, into which the sand from above the bridge and that scoured down in consequence of the new esplanade works, has been deposited.

In conclusion, the Author would point out that in his opinion the approaches of Dundee Harbour could have been materially improved by carrying out the works in accordance with the following plan:—

(1) The construction of the Tay Bridge with wide spans on the north or Dundee side.

(2) Dredging through the sandbank known as "My Lord's Bank" to the deep-water channel to the south-west.

(3) The removal of the Fowler and Beacon Rocks.

The Chief Engineers to the Dundee Harbour Trust have been: The late Mr. James Leslie, M. Inst. C.E. (1832–1846); the late Mr. Charles Ower (1846–1869); and the late Mr. David Cunningham, M. Inst. C.E. (1869–1896). The Author succeeded Mr. Cunningham in 1896, and held the office until his appointment to the Chairmanship of the Port Trust, Rangoon, in 1901.

The Paper is accompanied by fourteen drawings, from which Plates 1 and 2 and the Figures in the text have been prepared.

Discussion.

The PRESIDENT, in moving a vote of thanks to the Author for his interesting Paper, remarked that the Author was in Rangoon; but that his successor at Dundee, Mr. J. Thompson, Jun., was present, and might like to make some observations on the works described in the Paper. The President.

Mr. JOHN THOMPSON, Jun., mentioned that the coal-hoist jetties had now been completed at a cost of about £17,000, including the hoist and the foundations. The extension of the Caledon ship-building yard had been commenced. It was about 500 feet in length and about 150 feet from the shore. It was constructed of 12-inch piles, 8 feet apart from centre to centre, and 12-inch by 6-inch sheet-piles, with rubble backing and tie-piles behind the main piles. With regard to the movement of the sandbanks, he had not had much opportunity for making observations since taking up the position of Engineer to the Port. The Author attributed the removal of the Middle Bank to the narrowing of the river owing to the harbour-improvements, and its re-formation to the erection of the Tay Bridge, which had so diminished the flow of the ebb-current below the bridge as to allow material brought down by it to be deposited over the area of the Middle Bank. That bank had been in existence in 1816, and consequently must have been formed from other causes than the erection of the Tay Bridge. He quite agreed with the Author that the erection of that bridge had increased the flow of the ebb-current, doubtless owing to the narrowing of the river. The Middle Bank was practically in the same position now as it had been then, but farther northward and eastward. If the increased velocity of the ebb-current due to the narrowing of the river was sufficient not only to carry the material held in suspension above the Middle Bank, but also to scour it away, he did not think that the erection of the Tay Bridge would sufficiently diminish the flow of the ebb-current to cause the material brought down from above the bridge to be deposited on the Middle Bank. He thought it would decrease the velocity above the bridge and tend to increase the deposits there; and the slackening, for the same reason, of the flood-current as it approached the bridge would cause the material held in suspension on the flood-tide to be deposited over the area of the bank. From observations made by floats, the flood-current decreased Mr. Thompson.

Mr. Thompson. as it approached the Tay Bridge and increased after passing through it, and in the same way the ebb-current increased after passing through the bridge. Observations made by Mr. Cunningham had shown that there was not quite so much material in suspension on the flood-tide as on the ebb-tide; but there was a considerable amount, and he saw no reason why that material in suspension should not be deposited over the area of the Middle Bank now, as the tide slackened on approaching the Tay Bridge. Previously, no doubt, it had been deposited in Invergowrie Bay, farther west on the north bank. He thought the erection of the Tay Bridge was probably the cause of the re-formation of the bank, but not altogether for the reasons given by the Author.

Mr. Baggallay. Mr. H. C. BAGGALLAY thought there was no branch of civil engineering wherein practical experience was more important than in works connected with water. Theory was important, but practical experience was more so; and therefore he thought the Institution owed a debt of gratitude to any engineer who was good enough to present to it a Paper on works such as those described by the Author. The Paper was a little wanting in detail, and he thought some further information might be given as to the construction of the works. It was proposed to build a new wall in front of the existing berths on the north-east side, but nothing was said as to how the trade of the port was to be dealt with while that wall was under construction. It was mentioned in the Paper that the wall was to be of a permanent character, to replace the old timber wall: was it to be assumed that it was to be of concrete or of masonry? In dealing with a river with a strong current, and apparently with a bottom which was constantly shifting, anything like a cofferdam was a serious matter. In ordinary dock-work, in the dry, a timber quay could be built for about half the cost of a concrete or masonry wall, and there would be a greater difference when the work was carried out in a river where it was necessary to enclose it in some way. Therefore he thought some information as to how the work was to be carried out, and the trade of the port carried on in the meantime, would be interesting. With regard to the hydraulic installation, he congratulated the Author upon the very satisfactory performances of the jiggers. He had frequently kept a record of how many lifts cranes and other hydraulic machines made in discharging vessels. Of course it was more usual in dock-work where there were mixed cargoes to have cranes of about 30-cwt. capacity. These jiggers, however, being for a special purpose, dealt with only

5 cwt. The cranes in such ports as London, Liverpool, and Buenos Aires were usually 30-cwt. cranes, and he had found from observations on a large number, discharging different kinds of cargo, that they did not average more than thirty lifts per hour, or one lift in 2 minutes; whereas the jiggers could, when pressed, do about five lifts per minute, which was highly satisfactory. In the London Docks there were a number of jiggers, but they were not popular, as they did not answer well; that was probably due to the fact that the cargo to be dealt with was not always of the same kind. Where bales of jute weighing 400 lbs. were being unloaded continually, no doubt jiggers would be more useful. In the engine-house at Dundee there were two small accumulators. He had found small accumulators of little use; if an accumulator was to be used at all it should be a large one. An ordinary 30-cwt. crane hoisting to a good height used about 30 gallons of water at one haul, and the two accumulators mentioned in the Paper contained together only 50 gallons. It was a curious fact that, in dock-work, when the hydraulic installation was spread over a large area, accumulators were not wanted at all. Calculating what the expansion of the mains ought to be under the pressures given, it would be found that the expansion was something infinitesimal, one-thousandth or something very small. Whether it was due to the amount of air in the water or not, he did not know, but, as a matter of fact, constant pressure could be kept up without accumulators. Accumulators might be useful at distant points, but in those cases it was desirable that they should not be weighted up to the maximum pressure. If working at 700 lbs. per square inch they should not be weighted to more than, say, 600 lbs. per square inch, so that they might always be up. Generally, when there was a want of power, it occurred at a time when there had been a little falling-off owing to the over-use of capstans or machines taking a great deal of water, and the accumulators were found to be all down at the same moment; whereas, if the weight on the accumulators was kept low they were up until the pressure fell to, say, 600 lbs. per square inch. If weighted to the working-pressure they were always on the move, and that wore them at the top or bottom of the rams and caused them to leak; and if the glands were screwed tight they would not work at all when they came to the thicker part of the shaft. Therefore it was important that when accumulators moved they should move through as much of the stroke as possible, and not oscillate at the top or at the bottom. Although he had read Mr. Cunningham's Paper, he did not quite follow Mr. Baggallay.

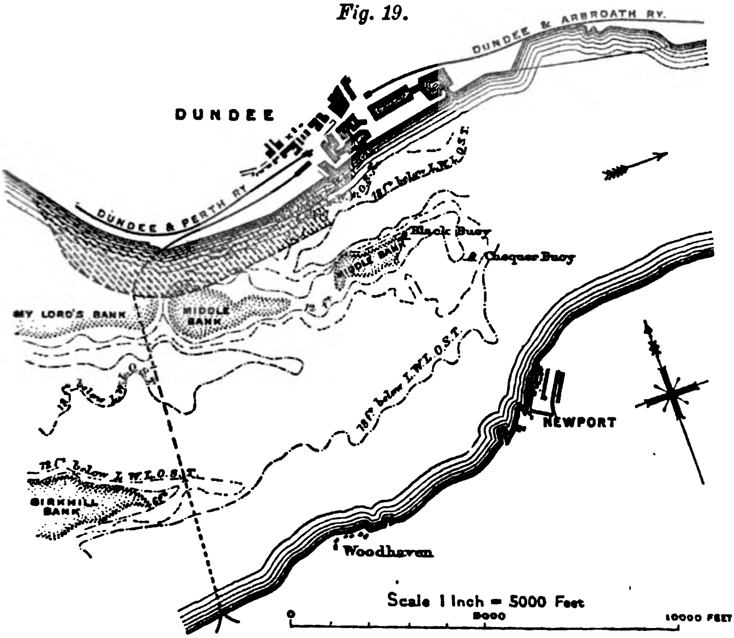
Mr. Baggallay. the Author in his views as to the cause of the ballast and sand coming in front of the docks. It appeared that, long before the bridge was made, what was called the ballast bank had had a tendency to come in front of the port. The illustrations did not give sufficient data to enable an opinion to be formed as to the actual direction of the current, but apparently there had been a large increase of depth in the estuary generally. Mr. Cunningham showed that in the 50 years about 30,000,000 tons of sand and silt had been removed; and while a considerable portion of that had been caused by the bridge, a much larger portion had been scoured away long before the bridge was built.

Mr. Pilkington. Mr. Woodford Pilkington remarked that he wished to express his appreciation of the Paper, which formed an interesting sequel to that written by Mr. Cunningham, and gave a historical survey of the progress of the Port of Dundee under the direction of various engineers. Whoever had been responsible for designing the Victoria graving-dock had put in a very interesting example of a caisson closing with a hinge, which he thought had been at that time a novelty. Since then much progress had been made with sliding caissons, floating caissons, and travelling caissons, especially the remarkable invention of the late Mr. Kinipple, M. Inst. C.E., who had shown Mr. Pilkington some beautifully designed automatic caissons. Mr. Cunningham's Paper was an able analysis of the regime of the estuary, and what puzzled Mr. Pilkington was that such a Paper should have been written without its Author leaving behind him any record of the manner in which he would wish to carry on the work of regulating the estuary. The laws which governed silting and the formation of sandbanks and bars in an estuary such as that of the Tay had been a peculiar hobby of Mr. Pilkington's for some time. He considered that a sandbank in the middle of a stream, such as "My Lord's Bank" and the Middle Bank, was the result of two meeting currents. If it were possible to find out where the currents came from a shoal could be dealt with much more easily. An important example of the formation of sandbanks by the deflection of colliding currents was afforded by the Goodwin Sands. These sands had been, as was well known, originally an island, the top of which had been washed away gradually by the sea; but they were now quicksands maintained by the currents, one current coming from the direction of Germany and another coming down the English coast. These currents met and divided, with the consequence that the Goodwin Sands had been formed; and it was surprising how slightly those sands had altered in contour and dimensions. This arose from

Mr. Pilkington

the currents, in again seeking the straight direction, meeting, the contained pointed oval being the permanent shape of the Goodwins. As was well known, cattle had fed on the sands some years ago, and there was no reason why they should not do so again if the sands were treated as the Admiralty had treated the mud-bank in Portsmouth Harbour called "H.M.S. Excellent." The plans in the Paper did not show the full length of the River Tay, but from the illustrations to Mr. Cunningham's Paper it appeared that there was one shoal by the Lady Buoy which was in the middle of the fairway—a shoal which must have been deposited

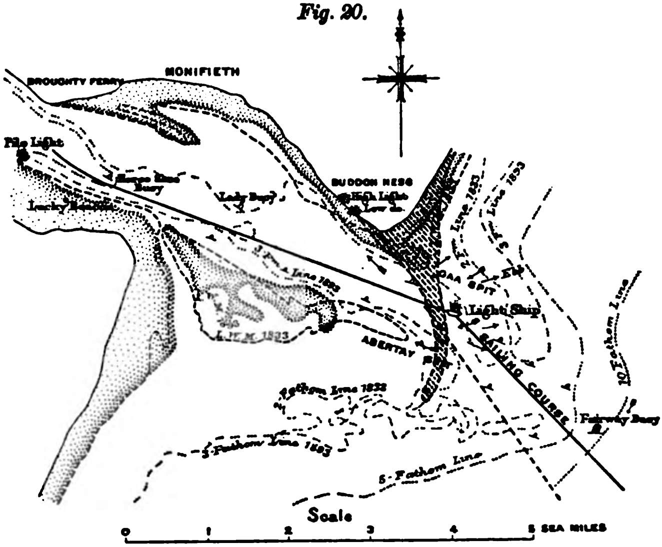
Fig. 19.



by the currents; and if it were removed it would never re-appear, there being no confluent currents in existence to cause its formation. That deposit had been formed of very large stones a long time ago. With regard to the Tay Bridge, in place of enlarging the spans of the bridge, which, on a curve having a radius of only 1,500 feet, would cause the bridge curve to be represented by a polygon of chord lines, so that the cross girders at the middle of each span would have to sail over considerably, and would require bracketing to support the curved rails, the effect of the piers could be overcome by advancing the line of the esplanade from the dock works and continuing it so as to intersect the bridge

Mr. Pilkington. at the end of the straight part across the river, the retaining-wall then curving in towards the shore, in the direction of Kingoodie, *Fig. 19*. This curved wall would act as a cushion and guide to the ebb current, which would wash away a large portion of My Lord's Bank and the Middle Bank. With regard to the removal of the bar, he suggested that this would be effected by a curved mole, or training-wall, and breakwater from below Buddon Ness, *Fig. 20*, passing inside the lightship and forming a mean of the curves of the littoral current lines of uniform soundings on the 5-fathom and 10-fathom lines. It was clear, from the description given by Mr. Cunningham and from the

Fig. 20.



results obtained, that the littoral current flowed always steadily from north to south; the effluent showed this from the permanent effort to follow it indicated by the sailing-course lines of 1833 and 1895 taking a permanent set south. The Abertay Spit as a centre of swing might disappear or remain, or alter in shape or in length, but need not be considered in designing the work, as an entrance 500 feet wide and having 35 feet at low water would be sufficient for any purpose. If that principle were carried out in the Tay estuary a curved junction would be made and the whole of the bar be removed; and instead of there being only about 14 feet of water over the bar at low water there would be 30 feet or 40 feet along the whole of the sailing-course.

Mr. S. G. HOMFRAY, in reference to the hydraulic machinery, remarked that the jiggers had been designed for the special work of lifting bales of jute, which were hauled up in rapid succession. The lift was merely a vertical one to the top of the gangway, and then the bales were slid ashore. The jiggers worked at the speed mentioned by the Author, and it was quite a different thing from working mixed cargoes with a swinging crane. They were most successful where there was no crane, as the men in the docks could never be persuaded to work jiggers when they could use a crane, the latter being a much easier method for them, although it did not work at the same speed. The 30-cwt. crane was very suitable for the goods that came into large British ports, and he had on several occasions timed 30-cwt. cranes making two lifts per minute. With regard to the size of the accumulators, the first accumulator had been put down for a very small engine. A second engine had been added, and another small accumulator had been put down to give the power: the whole formed quite a small installation. It had not been necessary to add largely to the accumulator-power for the sake of the jiggers, because, as Mr. Baggallay had mentioned, it was possible to do without accumulators. When a sufficiently large plant was worked, and where there were a number of machines lifting rapidly and constantly, the continual draft on the engine did away with the necessity for a large amount of accumulator-power, the accumulators being little more than equalisers. He thought, however, that even Mr. Baggallay, favourable as he was to large accumulators, would be satisfied that the coal-hoist was fairly equipped with an accumulator having a ram 20 inches in diameter and 35 feet stroke. With regard to the loading of outlying accumulators, Mr. Baggallay could not be contradicted in saying that it was an advantage that they should be loaded to a lower pressure, but what that pressure was to be depended entirely on the draft on the accumulator from the machines near, and could be settled only by experiment. The outlying accumulators should be practically always up, and should make a stroke only when a large quantity of water was drawn from the mains. Mr. Homfray.

Mr. F. E. WENTWORTH-SHEILDS remarked that the Author had given two interesting drawings of retaining-walls, a solid masonry wall, and a timber wharfing; but he did not mention in either case what the foundation was. The masonry wall appeared to be an exceedingly massive one, the thickness of the base being equal to quite one-half of its height, but the foundations appeared Mr. Wentworth-Sheilds.

Mr. Went-worth-Sheilds. to be shallow—only 3 feet 6 inches below the bottom of the dock—and it would be interesting to know on what the wall was founded, and whether any movement had been noticed in it. A somewhat similar wall had been built by the late Mr. Alfred Giles, Past-President Inst. C.E., at Southampton, and had been described in the Proceedings.[1] A certain length of it had moved. The foundations had been 6 feet in the ground, but the whole wall had slipped forward, due to the fact that it had been on what might be described as a very slippery, weak clay. The timber wharfing mentioned in the Paper appeared to be of a light character, and one that most dock-engineers would hesitate to erect, except on some exceedingly stable foundation; and it would be desirable to know into what the piles were driven, and whether there had been any settlement or forward movement. In regard to the neat and ingenious gate-caisson he also wished to know what method was used for opening and shutting it, and how long the operation occupied.

Mr. Napier. Mr. R. T. Napier mentioned that he had crossed the old Tay Bridge a fortnight before it fell, and the new bridge for the first time in August 1901, and he had naturally looked on the scene with interest. If he was not mistaken, he had noticed that the piers of the old bridge were still in existence in the river-bed. If the current flowed at right angles to the bridge, the piers would probably not be any additional obstruction, as the spans of the new bridge were the same as those of the old bridge, but otherwise they might be. In fact the matter would be complicated by the old piers being allowed to remain. If they were really there he would like to know whether there was any intention to remove them.

Mr. Shelford. Mr. W. Shelford thought it was possible to come to some important conclusions with regard to the movement of the shoals. The main thing was that in the Tay there had always been a middle sand, and that middle sand had asserted itself, though not always in the same position. The forces at work were generally, and to a large extent, similar to those in other rivers on the east coast. The prevailing north-easterly wind drove the flood-tide with considerable force against the shore of any river on the east coast, and the flood-tide then turned due west and flowed up the estuary. On its return the ebb-tide sought the shortest cut to the sea, flowing down the north side and making another channel; and the space between the two channels was generally called the middle sand. On the Humber, which was a good example of the east coast rivers, the same state of things was observed. Looking back at charts

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[1] Minutes of Proceedings Inst. C.E., vol. lxv. p. 171.

200 years old it would be found that the middle sand was invariably there, although not always in the same place, and it was always due to the causes he had mentioned. If the surveys were extended and the charts made more complete, he thought it would be seen that the theory he set up was correct. All other matters, such as the building of the Tay Bridge, and other obstructions, were subsidiary. Mr. Shelford.

Mr. G. F. DEACON considered that it was quite impossible to draw any conclusions without full information as to the estuary and a little more information as to the land water. Mr. Shelford's observations might be applied not only to the rivers on the east coast, but to some of the rivers on the west coast of England. There was an analogy, for example, between the Tay and the Mersey, the Mersey being an estuary running south-east, and the Tay an estuary of much the same size running south-west. In both cases the flood-current hugged the concave shore—Birkenhead in the one case and Dundee in the other—and in both, the ebb-tide took a straighter path, the cause and effect being the same. With regard to particular banks, much had been done by the straightening or curving of the shore on the Dundee side, and if the plan dated 1816 was compared with that dated 1900 the effect was obvious. Although the Middle Bank still remained, it was a much smaller bank, and the velocities had been increased considerably, with the result that the average depths shown by the sections had also been increased. He suggested the Paper should have added to it the figure of the inner estuary in order that it might be better understood, and also a little more of the mouth of the river.[1] Mr. Deacon.

The PRESIDENT explained that the report of the discussion would be sent to the Author, who would be asked to reply in writing, but Mr. Thompson might at once be able to give some information as to certain matters of fact which had been commented on. It was stated at the beginning of the Paper that protection had to be provided for vessels against the gales in the Tay, and perhaps Mr. Thompson could say whether the vessels lying against the quay-walls without any such protection suffered at all in times of heavy weather. The President.

Mr. J. THOMPSON, Jun., mentioned that no details of the proposed sea-wall had yet been prepared, but it was proposed that it should be built of concrete in short lengths of 200 feet or 300 feet at a time. The foundation of the Victoria Dock walls was rock, and the timber wharfing was on stiff clay. There had been no perceptible Mr. Thompson.

[1] A plan of the estuary of the Tay is given in Mr. Cunningham's Paper, above referred to; Minutes of Proceedings, Inst. C.E., vol. cxx. (Plate 6).—SEC. INST. C.E.

Mr. Thompson. movement in either case. He did not think there was any intention to remove the foundations of the old Tay Bridge. Large vessels were not affected in any way by gales, but the trawlers suffered. There had been no case of any vessel breaking adrift or damaging herself. On the average it took about 10 minutes to open the gate and 5 minutes to close it. The extra time taken in opening the gate was owing to the water in the air-tight compartment having to be displaced by means of an air-pump. This took on the average about 5 minutes. Under the most unfavourable conditions the time necessary for opening the gates was 13 minutes, and under the most favourable conditions 7 minutes.

The Author. The AUTHOR remarked, in writing, that, as the present engineer to the port had been present at the meeting when the Paper was read and had kindly replied to several of the questions raised, there was not much to add in reply to the discussion. The movement of sandbanks in an estuary was a subject on which it was almost impossible to find two engineers who thought alike, but the theories advanced in the Paper would, he hoped, serve as suggestions to others studying a similar subject. In connection with the Tay it was true, as remarked by several members, that there had always been a Middle Bank, but there were certain other facts which could not well be controverted. First, concurrently with the works of the port, the Middle Bank had decreased until in 1885 it had practically ceased to exist. Secondly, the bank had reasserted itself after the building of the new bridge and the whole of the river-bed in the vicinity and up to the line of the navigation-spans had begun to silt up; the inference from these facts being that the piers of the old and new bridges combined formed a groyne which obstructed the tidal currents and allowed sand to collect. With reference to Mr. Baggallay's remarks, the ballast bank should not be confounded in any way with the Middle Bank; the former was a distinct mass, formed below a projecting spur of land and had long since been entirely removed. In answer to the questions put by Mr. Wentworth-Sheilds, the piles in the timber wharf had been driven down to a very stiff clay. It was desirable to have the front of the market as near as possible to the river-front, and therefore it had been decided to limit the rows of piles to two, the back row also serving as foundations for the iron columns supporting the market-roof. He had recognised at the time that by this design the stability of the structure would depend almost entirely on the strength of the iron tie-rods, and these had been made very numerous and had been attached to the wharf with great care, the landward ends being embedded in blocks of concrete. Particular attention had

also been paid to the filling and hand-packing of stone pitching. The gate-caisson was opened and shut by means of chains attached to hand-power winches. Most of the piers of the old Tay Bridge were still in existence. A strong desire had been expressed by the Harbour Trustees to have them all removed before the building of the new bridge was commenced, but on the representations of the railway engineers that the foundations of the new bridge would be imperilled by their removal, they had been allowed to remain, on the railway company agreeing to place and maintain a light on each pier. The Author.

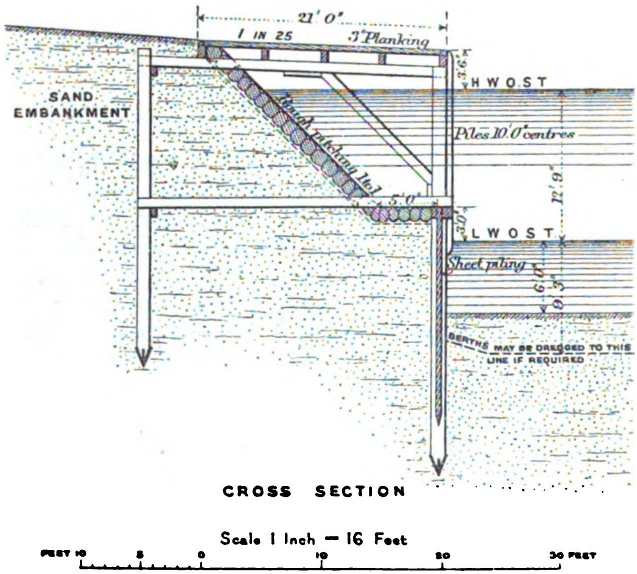
Correspondence.

Mr. T. JOHNSTONE BOURNE remarked that it would be interesting if the Author could give for the several critical periods at which increase of accommodation had proved necessary, viz., 1829, 1848, 1865, 1876 and 1891, the tonnage of goods, inward and outward, dealt with per lineal yard of quay. The length of quayage at those dates was given in the Paper, as were also the dimensions of the locks controlling the size of the vessels using the port; and the completion of the figures as suggested should show the increase of efficiency of unit length of quay as the average size of vessels increased. The shed-accommodation appeared to be about 8·6 square yards per lineal yard of quay, which seemed a low ratio, especially as the transit-sheds were of one floor only, which must serve for both export and import, and as there were no railway lines on the face of the quay. The design of the landing-wharf (*Figs. 9*) appeared to be of an eminently economical character. Perhaps the Author would state the nature of the material in which the piling was driven, and of the filling; and whether the anchor-rods occurred at every frame: also whether the anchor-block was continuous along the back of the quay. The figures given for the maximum and the average rate of discharge by hydraulic jiggers seemed to prove them to be as efficient as electric cranes for the kind of work required at Dundee, and their first cost was probably less. Mr. Bourne.

Mr. W. DYCE CAY observed that the section of the north wharf of the tidal basin for trawlers was the same as that of a wharf he had designed and erected in 1875 for herring-fishing boats at Mr. Cay.

Mr. Cay. Aberdeen (*Fig. 21*), except in the use of iron tie-rods at Dundee to carry the pressure of the embankment, and in the greater depth now required at low water. The requirements of the fishing-industry had been steadily progressive in the matter of depth of water and area of harbour. When he erected the above-mentioned wharf at Aberdeen, 6 feet at low water of spring tides had been considered sufficient to keep the boats always afloat; but, anticipating progress, he had made the work strong enough to admit of dredging the berths to 9 feet 3 inches. At that time the fishermen in many places had been contented with harbours dry at low

Fig. 21.



water. About 10 years later the size of the boats had been increased to 45 feet to 50 feet in length by 15 feet beam; and now the Moray Firth boats, of the "Zulu" type, were 60 feet long on the keel and 80 feet long by 20 feet beam on deck, and drew 9 feet to 9½ feet aft. As the hull cost £500, and steam-winch, sails, etc., a further £250, the owners naturally objected to putting the boats in harbours where they had to lie aground, especially if the bottom was rocky, or where they could not get in or out at all states of the tide; so that 10 feet at low water of spring tides was required. Also, with these deck-dimensions, twenty-seven boats filled 1 acre, or, say, twenty-two boats, to leave a little room for

working. The trawlers at Aberdeen and Dundee required, as stated in the Paper, 14 feet of water. With regard to the silting in front of the docks, he agreed with the second remedy proposed by the Author, viz., dredging through the sandbank called "My Lord's Bank," above the bridge, so as to lead more of the current on the ebb to the north side, and to make it sweep the face of the docks. He had noticed recently, when crossing the bridge, that on the flood there was a strong current passing through it at the smaller 130-foot spans objected to, so that he did not despair of the effect of the bridge if the channel above-mentioned were formed; and he thought that, by judicious dredging, the rate of silting and formation of the banks might be much reduced. Mr. Cay.

Mr. W. Leighton Jordan desired to point out, in reference to the Author's statement that the body of the tide ebbed on the south side of the river, and that there was a strong set of the flood-tide on the north side, that this course of the flood- and ebb-tides accorded with what he had lately described[1] as the normal course which they must have a tendency to take respectively. The estuary of the Tay, however, was a tidal river rather than an enclosed harbour of the character to which his arguments were intended to apply. The flood-tide from the north, after passing the headland on the north side of the river and taking its course southward in the offing, swirled back and recrossed the river's course at the bar in a northerly direction. The momentum of the flood gave it in fact several rebounds across the river's course before it reached Dundee, where the tendency of the ebb to the south side of the river, combined with that of the flood to the north side, seemed to show some controlling action of the normal tendency to cyclonic circulation. Mr. Jordan.

Mr. John Robinson remarked that for the development and prosperity of a port the equipment and the arrangement of the sidings, including their connection with the railways, were of great importance. The equipment of a port with the most efficient mechanical appliances was, in these times of quick despatch, necessary for dealing with the traffic, even although it might be somewhat costly; and an expenditure of as much as £12,500 or £15,000 in the construction of a hydraulic coal-hoist and the approach thereto might be justified. The hoist or tip referred to in the Paper as in course of construction by the side of the Tay, for shipping bunker-coal, provided for a Mr. Robinson.

[1] Minutes of Proceedings Inst. C.E., vol. cxlvii. p. 145.

Mr. Robinson. maximum height, between high water of ordinary spring tides and the discharging end of the shoot, of 37 feet, and at low water of 53 feet 6 inches; 40 feet above ordinary high water to the lower end of a coal-shoot was not uncommon inside docks, and 50 feet had been contemplated where bunker-coal was required to be tipped into the hatchways of large modern steamships when light. Wagons with end doors were used in the Dundee district, there being no hopper-wagons like those on the North Eastern Railway system, where the coal was dropped through the bottom doors of the wagons; in the present and similar cases the table, hinged in front of the cradle on which the wagons were lifted within the hoist, had to be tilted up at the back, after releasing the end door-catches, in order to discharge the coal. He had noticed on the ground that gradients were to be adopted for the full- and empty-wagon sidings leading to and from the hoist, the wagons entering and leaving the hoist at or near quay-level. This would lead to a saving in the working-expenses which would be well worth the cost of the gradients anywhere where the nature of the site available would admit of the necessary side slopes. He thought the curved sidings leading to the hoist for the full wagons would have been better laid out from the opposite or east side, so that locomotives, on bringing a train of coal-wagons from the collieries, would at once back them into the sidings with falling gradients towards the hoist, leaving them to be drawn forward by the hydraulic capstans when the coal was needed for shipment. Should the space not be required for other purposes, the sidings for empty wagons, being well located, could remain as they were instead of being altered to run alongside the suggested full-wagon sidings, but at a lower level. He had not noticed any provision for weigh-bridges, which many traders now considered indispensable for weighing both full and empty wagons as they went on and came off the cradle. The proposed method of placing the hydraulic lifting-cylinders vertically against one side of the framing, instead of under the cradle in a well below quay-level, would, he thought, fully answer the purpose. There were other situations, however, differing from Dundee, where a hoist erected on a quay-wall with telescopic side cylinders would be preferable to projecting, for a temporary convenience, a staging into the fairway in order to get the lifting-cylinders underneath the cradle, where the staging interfered with the entrance and departure of vessels. In any situation cylinders fixed on the framing had the advantage of being more accessible for examination and repairs. About 11 years ago, after the Barry Dock had been opened for traffic, divers had

Mr. Robinson.

been employed to perform some repairs in the well of a low-level hydraulic tip, one without a water-tight iron casing enclosing the ram, etc., and a considerable amount of time had been spent in getting the tip into working-order again. It had occurred to him then that the hydraulic movable tip on the south side of the dock had its cylinders hung up in the framing; why not, he had thought, place the cylinders of a fixed tip above ground, securing them to the framing, thus obviating the necessity for any inspection and repairs being done by divers under water? He had mentioned the matter to the managing director, who, at the fixed tips subsequently erected by the side of dock No. 2, had had the hydraulic cylinders for lifting and tipping attached to the sides of the steel framing above quay-level, and the working had, he understood, given satisfaction. He had witnessed the method of discharging jute-bales by lifting them from a vessel by means of a rope attached to a hydraulic jigger stationed on the wharf and passing over a pulley suspended from the ship's derrick over the hold, and then disengaging the bales and allowing them to slide down a smooth wooden inclined plane into the shed; and he had seen that it was very expeditious. By the side of the Victoria Dock there was a 90-ton crane, and on the day of his visit a boiler weighing 83 tons had been lifted into a steamship. Transit-sheds being essential to the trade of Dundee, the Harbour Trust had not hesitated to build them of a substantial character, which had been done at a reasonable cost. He had scrutinized the granolithic flooring in the sheds recently erected, and in his judgment it was very suitable for the purpose, and equal to the traffic it had to sustain; there was, however, some danger of fracture from subsidence where the floor and walls were on made ground. In proposing to construct a new river-wall, having a dredged depth alongside of 27 feet at low water of ordinary spring tides, the Harbour Trust was providing for the accommodation of the large modern cargo-steamers which certain shipowners and merchants required for the profitable carrying on of their business. At high water of ordinary spring tides the depth of water in the Victoria Dock, the last constructed at Dundee, was 21 feet, and in the Earl Grey Dock, previously constructed, only 17 feet 6 inches at springs, and 14 feet 6 inches at neaps; there was therefore good reason for the provision of a greater depth of water. But the best way of arranging for the accommodation of vessels of a deeper draught than those making use of the existing docks, of such limited depths, required careful consideration as to whether it should be by a deep-water wharf-wall on the Tay side, or by a deeper dock;

Mr. Robinson. because the construction of a permanent wharf-wall 2,000 feet in length, with foundations more than 27 feet below low water of spring tides and 43 feet 6 inches below high water, in the situation proposed, would be very costly, and as great a depth would also have to be maintained along the navigation-channel and over the bar. Although the present timber wharf might allow the largest steamers now frequenting the port to lie and discharge at any time of the tide without inconvenience, there was a depth of only 18 feet at low water of spring tides, which limited the draught of vessels at such times, except when the level of the fresh water of the Tay happened to be higher; and at ordinary spring tides there was a variation in the level of the water at the river-wharf in one day of 16 feet 6 inches, whereas in the docks the variation in the level in a whole week was only 3 or 4 feet, that was between high water of ordinary spring and neap tides. Again, vessels lying at the proposed new river-frontage, 140 feet farther out into the Tay, would be more subject to the influence of the flow and ebb of the tides, and would be more exposed to gales of wind, which at times were very severe in the estuary of the Tay. Under these circumstances a dock would be more convenient for loading and discharging the cargoes of vessels; it would also be less difficult to construct, would probably cost no more in the end, and would be better value for the money. A timber wharf on the site proposed for the wall would not be so difficult to carry out as a wall, and consequently would be a more economical structure, taking into consideration the cost of the material as well, if the latter were not liable to destruction by the *teredo navalis*. But a deep-water dock, well equipped with up-to-date appliances, would give the most satisfaction in the management of the traffic, and be more conducive, in his opinion, to the prosperity of Dundee. With regard to improvements in the approaches to the harbour, the existing conditions would have to be studied, including the effect produced by the Tay Bridge on the tidal currents and fresh-water floods, as neither the site nor the openings could well be altered. Doubtless the conditions would have been different had there been no viaduct across the estuary, but the difficulty of devising works for the prevention of the encroachment of sand on the navigable channel had not been rendered insuperable thereby; and after giving due consideration to improvement schemes and to their various bearings, all the changes in the sandy estuary following the carrying of them out might not be foreseen. The unfavourable effects, however, might have a remedy devised for them before much mischief had been done. He did

not think that the flow and ebb of spring tides, or the scouring action of great land-floods at the ebb of spring tides, referred to by Mr. Cunningham in his Paper, could be depended on for keeping open a deep navigation-channel and the bar at the mouth without dredging, even if the channel were properly and scientifically treated. Vast improvements might be effected in the approaches to the harbour with modern suction sand-pump dredgers, judging by the success of their employment at Liverpool and at a number of foreign ports. A greater depth of water, he considered, was requisite for the accommodation of vessels of larger size if the trade of the port was to be retained and increased. The Author had given the cost of the different works executed in a way which would be easily understood and appreciated by dock engineers. Mr. Robinson.

Mr. W. Stopford Smyth observed that the estuary of the Tay afforded a most interesting study, and was a striking object-lesson in the evolution of docks, besides being a typical instance of the rapidity with which the demands had grown for accommodation on a wider and more extended scale than even the most sanguine minds had foreseen. The Port of Dundee might also be taken as an instance of the truth of the maxim that if proper accommodation were made, adequate means employed, and due equipment provided, then successful results might be looked for with considerable confidence. It must be admitted, however, that some instances could be named of docks having been constructed with too much precipitation, on an ambitious scale and in inviting situations, where the hopes of the projectors had not yet been realised. The large volume of the upland water, the comparatively vast width of the estuary opposite Dundee, the characteristic "neck" at Broughty Ferry, and the reversed inclination of the low-water surface during neap tides were the most salient features; while the fluctuation in quantity of the upland water affected the position and extent of the shoals in front of the entrance to the docks at Dundee and the depth on the bar. The docks first constructed were so small, the entrance was so narrow, and the depth of water on the sill was so little, that at the present day they stood but as ancient records, no longer remunerative, upon which much capital had been expended. The extremely cautious steps by which the Dundee Trustees had increased their dock-accommodation were very noticeable, but the boldness with which they had abandoned the use of docks for large vessels, and were building quay-walls in the tideway at which to load and discharge, notwithstanding the strong currents and in the face of the gales to which the estuary was subject, was much to be Mr. Smyth.

Mr. Smyth. commended. The fact having been generally accepted that vessels of large tonnage were, and would continue to be, the preferable means of transport across the ocean, it had been recognised that it was essential that facilities on at least an equal scale should be provided for unloading and discharging. Thus, a depth of 30 feet at least must be provided, and the loss of time consequent upon the necessity of entering docks and the delay in locking out must be avoided, the loss by such detention often amounting to a considerable sum. The Port of Dundee, by providing quays in the open, was fairly in advance of most other ports, being able to offer berths which could be reached without the delay occasioned by locking, and where large vessels could be loaded and discharged at any state of the tide without inconvenience. The mode of discharging general cargo was antiquated and far from being economical, but of course it could readily be improved by the adoption of proper methods. The question of dry docks for the use of vessels frequenting the port remained for solution. The Victoria dry dock was altogether unapproachable by large vessels, and was wholly inadequate to serve the needs of the present day. Floating docks offered advantages which the graving-dock could not afford, permitting ships' hulls to be examined at short notice when desired, and to be repaired and coated with the least possible delay. The very magnitude of a floating dock capable of taking a vessel of large size enabled it to withstand the winds and currents peculiar to what, in the case of small vessels, would be termed an exposed position. The configuration of the estuary had to be kept distinctly before the mind when considering the subject as a whole. From the mouth of the River Earn, where the width was about 600 yards, the estuary widened gradually for a distance of 10 miles, to Balmerino, where the width was $2\frac{3}{4}$ miles. The shores then converged for a distance of 2 miles, to the point where the Tay Bridge crossed the estuary, which was there $1\frac{1}{2}$ mile wide. The shores were nearly parallel for $1\frac{1}{2}$ mile below the bridge, but immediately and suddenly contracted to a width of $1\frac{1}{4}$ mile opposite the entrance to the Camperdown Dock, which was $1\frac{3}{4}$ mile below the Tay Bridge. From the dock entrance to the "neck," a distance of $2\frac{1}{2}$ miles, the shores again converged. At the neck the width was $\frac{3}{4}$ mile. From that point the estuary widened, till, at a distance of $2\frac{1}{4}$ miles farther, where the southern shore ceased, the width was $2\frac{1}{4}$ miles. The northern shore trended eastward 3 miles farther. The channel extended due east for a distance of 6 miles from the neck, then bore south-east for 2 miles to the existing bar, where the depth at low water was reduced

to 19 feet. The flood and the ebb took separate courses up the channel, as was usually the case elsewhere; the flood running unobstructedly on the north side, and the bulk of the ebb-tide on the south side, but failing to keep clear the entrance to the deeper docks, the depth there below low-water level being only 6 feet. Sandbanks necessarily occupied a zone between the two channels. Between the Tay Bridge and the dock-entrance, sandbanks occupied the north side, and the main channel was well to the south, giving a depth of 29 feet at low water for a width of 400 yards, close to Newport on the south shore. The course of the ferry-steamers between Newport and Dundee on the north was much obstructed by the tail of the Middle Bank, and by the Beacon Rocks, which were about 200 yards from the outer line of the Dundee docks. The Newcome Spit projected from the south shore half-way between Newport and the neck; the main channel was thereby driven diagonally to the north. At the neck the channel was 800 yards wide, with a minimum depth of 30 feet at low water, and was free from sand. The Horse-Shoe Spit projected from the north shore, turning the sailing-channel again southward and contracting it, at 1½ mile from the neck, to 200 yards in width, with a minimum depth, at low water, of 28 feet. The sailing-channel then expanded, and was again contracted in width to 200 yards, 2 miles farther down, by a hard patch. Beyond the patch deep water extended right away to the bar, 8 miles from the neck. The bar had been moved 1 mile seaward since the date of the first reliable survey, 1883. The material forming the banks and shoals varied. In the upper part of the estuary banks of fine sand, mainly on the north side, covered many square miles. Large quantities of such sand had been taken down by the ebb-tide. There were also sandbanks within the main channel of the upper reach, composed of coarser and cleaner sand than on the extensive flats to the north, the main channel having varied little above the Tay Bridge. Between the bridge and the dock-entrance the bank was of fine sand. The Newcome Spit, as well as the Horse-Shoe Bank and the hard ridge, consisted largely of coarse sand, full of water-worn granite boulders. Before the construction of the docks the Middle Bank had occupied that position in the centre of the channel to which it owed its name. It had been then, and as late as 1833, abreast of the bight between Newport and Woodhaven on the south shore. At the date mentioned the earlier docks had been made, but the downward movement of the ballast bank had already been apparent, the entrance to the docks having been even then impaired by the quantity of sand and silt deposited in front Mr. Smyth.

Mr. Smyth. of the harbour. At the period referred to, when the bar had been nearly 1 mile nearer the shore, the entrance from the sea had been more clearly defined, and the Newcome Spit had been nearly ½ mile higher, and had projected so far north that a curved channel, less than 500 yards wide, had caused occasional grounding of large vessels, the depth on the bar at low water being then 16 feet. The extension of the docks, the frontage of which projected ½ mile into the estuary, and the construction of the Dundee and Perth Railway embankment, had caused, by the year 1869, some apparent reduction of the Middle Bank in midstream, but the crest had then been moving northward and eastward and the accumulation of silt in front of the docks had much increased. The first Tay Bridge, commenced in 1871 and destroyed in 1879, had been supported on the north side by piers set square to the centre line of a curve of 20 chains radius, in spans of 67 feet. The esplanade to the west of the docks, built about this time, trended, unfortunately, in a direction opposite to that most conducive to the maintenance of the requisite depth of water in front of the docks. These structures, as they existed, were detrimental and prejudicial to the interests of the docks, for although the piers of the first bridge had been removed, those of the second had been similarly placed in relation to the stream. The result was that, since 1879, the main current of the ebb had flown through the thirteen navigation-spans, while the area immediately below the twenty-five small spans had been slack water, and had permitted silting; the contour of the esplanade wall assisted in leading silt from the ballast bank to the front of the docks, there to be deposited in the slack water. In consequence of the failure of the ebb-tide to carry forward the silt, dredging had had to be resorted to in front of the docks. Notwithstanding the large amount of dredging, the Middle Bank had been in 1879 more threatening to the well-being of the docks than before the erection of the bridge. The subsequent construction of the wharf-wall to the east of Dundee, at which the largest steamers lay and were discharged at any time of the tide without inconvenience, had tended to improve the current and to reduce the accumulations in front of the docks. No doubt when the temporary timber wharf had been replaced by a quay-wall the effect of the current upon accumulations of silt would be somewhat increased, but the general conditions and consequent deposit of silt must continue unless more active measures were employed. The action of the flood and ebb on the outermost reach of the estuary influenced the whole regime, and was therefore worthy of particular attention. While the bar has been carried

seaward during the past 60 years, the sandbanks on each side of the main channel had been equally extended by deposits of sand brought down by the ebb from the upper reaches. The sandbanks from the points where the mainland ended were far from being in a condition to keep the channel in its proper course or to allow the ebb to have its full effect. Part of the ebb escaped over the Gaa Spit, 2 miles above the bar. The tide in entering the mouth of the estuary flowed at first in three directions, viz., over the bar, across the Gaa Spit from the north, and through an opening in the Abertay bank from the south; and it entered the last-mentioned with great force. To provide access to the docks and to allow large vessels to approach the port at all times the following modifications appeared to be necessary:—(1) The formation of an embankment of large rubble stone in front of the esplanade to half-tide level, laid so as to form, with the portion of the present esplanade wall close to the Tay Bridge railway station, one continuous straight line. (2) The removal of the Beacon Rocks. (3) The removal by dredging of as much of the Newcome Spit, the Horse-Shoe Bank, the Lady Bank, and outside it, as might be sufficient to form a channel to give a depth of 30 feet at low water. The material to be thus raised by dredging, consisting largely of coarse sand full of water-worn granitic boulders, should be applied to the following purposes:—(i.) A line of training-wall between East Newport and Woodhaven, forming the chord of the bight between those two places. The ebb-current would then have greater effect along the north shore, and the deposit of silt would be checked there. The ferry landing-place could be transferred to East Newport without causing much inconvenience to passengers. (ii.) The formation of half-tide training-walls on the flats of the sandbanks of the Gaa and Abertay Spits, so as to secure the full effect of the latter half of the ebb over the bar. With a contraction of the estuary and an unobstructed channel between the Tay Bridge and the docks, and between the neck and the sea, the full advantage of the ebb-currents during land-floods would be obtained over the bar, which would thus, in all probability, be reduced to 30 feet below low-water level. Further dredging would be required alongside the new quay-walls to the east of Dundee to allow the vessels of the immediate future to berth there. Possibly periodical dredging might be required on the bar to maintain the 30 feet at low-water level. If the half-tide rubble wall were formed west of Dundee to prevent the ballast bank from being carried down to the entrance to the docks, the dredging there would be Mr. Smyth.

Mr. Smyth. reduced to a very small quantity, and the condition of the estuary would become balanced and its working almost automatic.

Mr. Wheeler. Mr. W. H. WHEELER remarked that the Paper, taken in conjunction with that by Mr. Cunningham, afforded some instructive lessons on the effect which works of improvement carried out on the foreshore or bed of a river had on the propagation of the tidal wave and the maintenance of the navigable channel. It appeared from these Papers, that some time previous to the year 1833, works had been carried out on the foreshore of the river between Perth and Dundee with a view to the reclamation of a large tract of tidal land, which had led to the accumulation of between 13 million and 14 million cubic yards of alluvial matter, and the decrease to that extent of the volume of tidal water flowing into and out of the upper part of the river. Fears had been entertained by the harbour authority, that this large abstraction of tidal water would lead to deterioration of the navigable channel, and Mr. James Walker, who had been consulted, had confirmed those fears and had advised that no further reclamation-works should be permitted. Soon afterwards works had been carried out in the same part of the river for the improvement of the navigation by regulating the course of the channel, and removing 840,000 cubic yards of material from the bed of the river, a uniform depth of 5 feet at low water and 15 feet at high water being secured. The result of this dredging and improving the channel had been that the low-water level had become depressed 2 feet, and the velocity of the flood-tide had been increased 1¾ mile per hour, causing it to reach Dundee earlier than before the commencement of the works; the level of high water at Perth, which previously had been level with that at sea, was now 9 inches higher. The volume of tidal water flowing into and out of the river above Dundee had been increased by 20 million cubic yards. Careful surveys of the channel and sandbanks had been made before these works were carried out and afterwards, and it had been reported to the Commissioners,[1] that although large deposits had taken place on the sides of the river, this effect had been more than compensated by the increased volume of tidal water, due to the deepening of the navigable channel, and by the scour of the ebb and flow of the water being increased and intensified in action; and that the alterations which had taken place in the channel between Perth and the sea were all in the direction of improvement. Extensive encroachments had

[1] Report of Mr. David Cunningham to the Trustees of the Harbour of Dundee, 1887.

also been made on the foreshore of the river for the docks at Dundee, and in the construction of a wall and promenade 3 miles in length. The width of the waterway of the river had been reduced from 1¾ mile to 1½ mile, the total area of land abstracted from the foreshore amounting to 328 acres. The piers of the Tay Bridge constructed in 1871–78, which crossed the channel near Dundee, further decreased the waterway by nearly ⅛ mile. These encroachments and restrictions of the waterway had led to increased velocity of the current passing Dundee, and a consequent deepening of the channel and scouring away of a large middle sand, which had previously extended over an area of 130 acres, and had risen 8 feet above low water, the depth in the channel increasing to 30 feet where the sand had formerly dried at low water. The depth of the water through the piers of the bridge had been increased 8·8 feet. The greater part of the sand set in motion by the scour due to the increased velocity of the current was carried away on the ebb to sea, but owing to the piers of the bridge being so aligned as to divert the flood and ebb current away from the north side of the river, some deposit had occurred in the slack water in front of the harbour, and 1½ million cubic yards had had to be dredged in order to obtain sufficient depth for the entrance to the docks. This depth had since been maintained. It appeared, therefore, that, contrary to the opinion so frequently expressed as to the injurious effect, on the bar and channels of a sandy estuary, caused by diminution of the area and abstraction of any part of the volume of tidal water flowing in and out of such estuary, no deterioration of the bar at the mouth of this estuary had taken place, due either to the reclamation-works in the upper part of the river, or to the abstraction of foreshore for the Dundee harbour and river-wall. On the contrary, a careful comparison of the surveys made on various occasions between 1833 and the present time disclosed the fact that the diminution in area had been more than compensated by the improvement in the channel, the depth of water over the bar having gradually increased till there was now between 3 feet and 4 feet more water over it than there had been formerly; and that it had moved nearly 1 mile seaward. Another fact disclosed in these Papers was contrary to the theory, so frequently advanced, that sand and other deposited materials was brought into estuaries from the sea by the flood-tide. Mr. Cunningham in his Paper stated that the sea-water entering the estuary on the flood-tide over the bar, was of a "clear bright-green colour," whereas the ebb-water in land-floods which it met on its course down the channel, and under which

Mr. Wheeler.

Mr. Wheeler. it forced its way like a wedge, was turbid and of a purplish-brown colour. Mr. Wheeler's own experience of examinations of the sea outside the bars of many sandy estuaries confirmed the fact mentioned in the Paper, as he had invariably found the water in these localities clear and bright, except when discoloured by heavy land-floods.

The Author. The AUTHOR, in reply to the Correspondence, regretted that, as he had now severed his connection with Dundee, he was unable to give the information as to tonnage of goods asked for by Mr. Bourne, and otherwise to reply so fully as he would wish to the remarks of correspondents. The sidings in connection with the coal-hoist, referred to by Mr. Robinson, had been designed to meet the requirements of the railway companies, and after consultation with their engineers. The 90-ton steam-crane at the Victoria Dock was admittedly behind the times, and shortly before leaving Dundee he had prepared a scheme for a 120-ton derrick-crane on a proposed new riverside wharf. The question of deep-water dock *versus* deep-water river-wharf was one which had had the earnest consideration of the Harbour Trustees and their engineering advisers for years. In 1873 the late Mr. T. E. Harrison, Past-President Inst. C.E., had prepared designs for a new dock, extending into the river and embracing the Fowler and Beacon rocks, at an estimated cost of £450,000, and in 1883 the Harbour Engineer (Mr. Cunningham) had submitted a scheme for a wet dock on the site of the present shipbuilding-yards at a cost of £405,000. In each case want of funds had been the chief obstacle to the execution of the works; and on a review of the whole situation in 1891 it had been decided that a wet dock was financially impossible. Dundee was a port which had now seen its best days and had no prospects. It was a town with practically only one trade, viz., the manufacture of jute goods; and now that Calcutta had built mills and manufactured jute goods on a large scale, Dundee was greatly handicapped and the competition became more severe every year. It might be said that Dundee was geographically the natural port for a large portion of the east coast of Scotland and should have a large import trade, but, as a matter of fact, Leith monopolized the trade, and from Leith as a centre goods were despatched by rail all over the eastern counties. Under these circumstances the Harbour Trustees had had to provide accommodation for the larger class of ocean-going steamers at the least possible cost, and deep-water river-wharves had been decided upon. The Trustees did not regret their decision, and shipowners and shipmasters were unanimous in preferring the

wharves, and grumbled if they were sent into dock; while the size of modern vessels precluded them from all danger from gales of wind in the estuary. He had recently had a similar problem before him at the Port of Rangoon, and, partly owing to the absence of any sort of foundation for dock-walls or material for building the same, and partly owing to the great success of the river-wharves at Dundee, he had decided at Rangoon in favour of river-wharves as against a dock. The remarks of Mr. Smyth were of considerable interest, but the Author doubted whether in the Tay the practical benefits of the training-walls recommended would be commensurate with the expenditure in their construction. On the North Bank he deprecated any alteration or extension of the existing esplanade, for the reason stated in the Paper. The points of resemblance between the north wharf at Dundee and Mr. Cay's wharf at Aberdeen appeared to be too remote for purposes of useful comparison. At Dundee the depth from high water to ground level was 28 feet 6 inches as compared with 18 feet 7 inches at Aberdeen; and whereas at Dundee the width of quay was 12 feet and the bank was kept up artificially, at Aberdeen the width was 21 feet with a reduced slope; further, the embankment was in the one case soft mud and in the other sand. The Author.

18 February, 1902.

CHARLES HAWKSLEY, President,
in the Chair.

(*Paper No. 3331.*)

"Electrical Traction on Railways."

By William Morris Mordey and Bernard Maxwell Jenkin, M. Inst. C.E.

The recent arbitration as to which of two systems should be adopted for the "Inner Circle" line of the Metropolitan and Metropolitan District Railways has raised many questions, one of the most important being whether electrical working of railways has yet reached such a stage of development that it is ripe for application to main lines and to the railway systems of the country generally.

A very interesting stage has been reached in the development of electric railways. For short and busy lines, electricity has now shown that it is able to supersede steam. The present seems a suitable time for a general review of the principal systems of electrical traction that are in use or that may be regarded as practicable, and for an examination of the advantages and disadvantages of each, keeping especially in view the qualities that seem essential, or at least desirable, for general railway work. If such an examination shows that, however suitable existing systems may be for short lines, or in special instances for long lines, none of them contains the essentials for success in main-line and general work, a useful purpose may be served, if only by indicating what difficulties still remain to be overcome.

The subject of this Paper is primarily the consideration of questions affecting railways as usually understood; but some of the matters dealt with apply equally, and all in some degree, to tramways. There is no natural distinction between electric railways and electric tramways; in practice they often merge into each other, a street tramway line becoming a railway when it traverses the open country.

Methods of electric-railway working may be divided into three classes:—

1. Continuous-current methods.
2. Composite continuous - current and alternating - current methods.
3. Alternating-current methods.

This classification of the methods is in the historical order of their development.

Continuous-Current Systems.

The ordinary two-wire 500-volt continuous-current system, similar in all its essentials to the ordinary electric tramway system, has been used with success for many years on the Liverpool Overhead Railway,[1] on the underground City and South London Railway,[2] and more recently on the Waterloo and City Railway,[3] as well as on lines in Chicago and other places. The pressure of 500 volts has become a standard in tramway and railway work, because, among other reasons, it presents no serious difficulties in the making or the working of the apparatus, or in the insulation of the conductor, and because it is not high enough to be dangerous under any ordinary conditions of working. With increase of distances or with heavier traffic has arisen the necessity for higher pressures than 500 volts, in order to keep down the cost of the transmission-lines.

For railway work, where the live conductor is a rail near the ground, the danger for any given pressure is clearly greater than with an overhead wire, as the conductor is more accessible. For this reason (and because of official restrictions based thereon) this standard pressure of 500 volts has been adhered to for railways, although in the large motors used in such work it would be possible and practicable to employ a somewhat higher pressure. Apart from the question of danger, the chief objection to a higher pressure with continuous currents is that the commutators of the motors, and in a less degree of the dynamos, would have a tendency to cause more trouble by sparking. With extreme variations of load and under traction conditions, it is not possible at present to get sparkless working of commutators; and the higher the pressure, the greater is this difficulty.

So long as 500 volts is adhered to as the working-pressure for the motors, and so long as continuous currents are used throughout, the practical alternatives to the simple 500-volt two-wire system are not numerous. They are:—

[1] Minutes of Proceedings Inst. C.E., vol. cxvii. p. 171.
[2] *Ibid*, vol. cxii. p. 209.
[3] *Ibid*, vol. cxxxix. p. 56.

(*a*) Some form of the Hopkinson three-wire system.
(*b*) Two-wire system with generation and transmission of high-tension continuous currents, and continuous-current converters for reducing the pressure; or some arrangement for raising and lowering the pressure to and from the transmission-lines.
(*c*) Combination of (*a*) and (*b*).

(*a*) The three-wire system has some important advantages. It enables transmission to be effected economically to much greater distances than with the ordinary 500-volt system. It allows ordinary 500-volt apparatus to be used, in some cases without any change in the cars or trains. It is, therefore, a matter of surprise that it has not come into more extensive use. There is no example, in this country, at least, of a simple three-wire 1,000-volt tramway or railway system—there does not appear to be one anywhere. The system is used, however, on the City and South London Railway (to be referred to later), in combination with continuous-current high-tension transmission. The essentials of the three-wire 1,000-volt system as applied to traction are: the use of double the motor voltage, by arranging 500-volt motors or groups of motors in series; and the use of a middle conductor, at earth potential, to carry any current required to balance the two sides of the system, and to keep the maximum pressure between any live conductor and earth the same as in the two-wire 500-volt system.

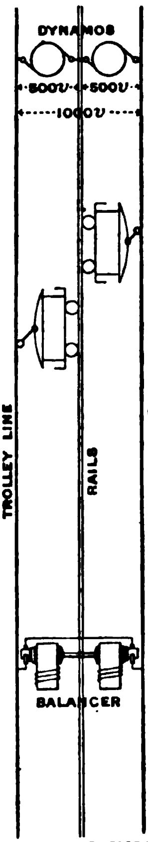
It has sometimes been proposed to have both sides of the system on one train, having one or more motors on the positive side connected in series with the same number on the negative side; the middle point can then be connected with the rails, which would have to carry only the out-of-balance current; or, alternatively, an ordinary balancer-set might be carried on the train, so as to save the cost of bonding the rails. Probably in most instances the motors could be left to balance themselves, the same number of similar motors being always used on each side. In any case, the middle point of the system must be maintained at earth potential, if the voltage to earth is not to exceed that in the two-wire system; but this can always be effected equally well at the generating-station. It will be observed that in such a system, in order to obtain the advantages of series-parallel control, not less than four motors or at least two double-commutator motors must be used on each separate running unit.

The great objection to a system in which the train takes current at the full voltage from both of the outers of the three-wire system

is the necessity it involves of using two live conductors, either overhead or on the track, with the consequent complications of double collecting-arrangements and risks of short circuits.

Although it has been in use to a limited extent for some years at 500 volts, the double-trolley two-wire system has not spread in tramway work. Its extra overhead complications and increased liability to short circuits seem to outweigh the advantages it possesses in allowing a greater drop of pressure, in dispensing with the rails as a return conductor, and in avoiding earth leakage and electrolysis. The experimental line from Earl's Court to High Street, Kensington, on the District Railway, which was a two-wire system, showed that a 500-volt double-insulated system on the track level is at any rate feasible; but in a three-wire 1,000-volt system the pressure between either of the conductors and earth would be double that of a two-wire 500-volt system in which the middle point was effectively maintained at earth potential. Unless, however, this is effectively done, the negative of a two-wire system in practice would go to earth potential; so that the maximum voltage to earth (that of the positive conductor) would be the same in the two-wire 500-volt system, as in the three-wire 1,000-volt system. Hence, so far as regards the giving of shocks to workmen the three-wire 1,000-volt system is exactly the same as the 500-volt two-wire system. A 1,000-volt system with two insulated conductors, either overhead, or at the side of the line, or at the rail-level, would present serious if not insurmountable difficulties when applied to complicated junctions and yards. These difficulties could to some extent be reduced by having one of the live conductors at the rail-level and one overhead. But for any lines through the open country a live rail is not likely to be used even at 500 volts—the risk of accident and interruption would be too great.

Fig. 1.



THREE-WIRE SYSTEM

The 1,000-volt three-wire system, however, does not necessarily involve the use of double-trolley wires or live rails, even on a single track. For double tracks the arrangement is very simple,

as shown in the diagram (*Fig. 1*). Two single-trolley lines (or their equivalent) are used, one for each track, with 500 volts pressure between each wire and earth, but with 1,000 volts between the two wires, the rails being used as the common or "middle" conductor.

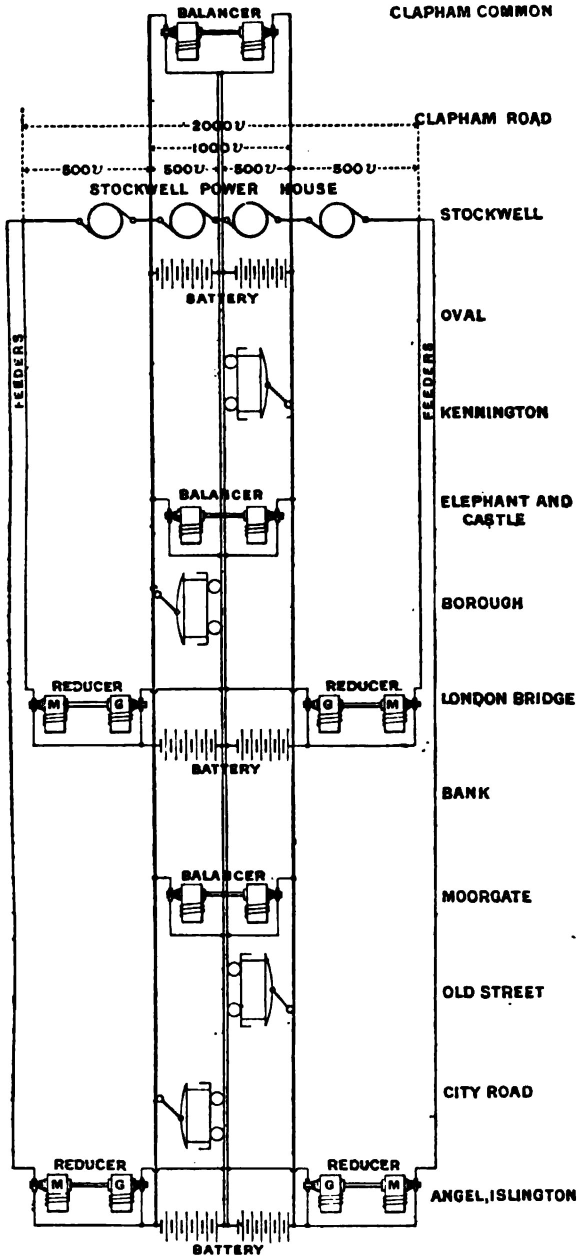
The 1,000-volt three-wire system may be used on a single track with only one trolley-wire, if the line is divided into at least two portions; which should be arranged so that their loads approximately balance each other, otherwise large balancers may be necessary. With this arrangement the rails transmit the current between the cars on the two portions, as well as any difference of current to or from the balancing-point. Where there is an up and a down service on a single line, with crossing-places or turnouts, then a possible way of working the three-wire 1,000-volt system, with reduced need for balancing and with reduced distances for the current to travel by the rails, would be to have two live conductors but only one trolley or collector on each car or train, the up cars or trains using one conductor, and the down cars the other. Reports of attempts to use the 1,000-volt three-wire system on tramways in America state that it failed mainly on account of the difficulties of balancing the two sides. It is satisfactory to find that on the City and South London Electric Railway no difficulties have been experienced from this cause.

(*b*) The second alternative to the simple 500-volt two-wire system is the addition thereto of the generation and transmission of high-tension continuous currents, with reduction by continuous-current converters to 500 volts for the trains. This system, which apparently has hardly been used, with primary and secondary circuits entirely separate, offers no advantage over a combined alternating- and continuous-current system with motor-generators.

(*c*) The third alternative is a combination of the three-wire 1,000-volt system—with increased pressure for transmission. This plan, which is in use on the City and South London Railway, is an interesting one for several reasons, and deserves careful study. It may be described as a three-wire 1,000-volt system for the two tracks, with a five-wire system of transmission to distant points at an effective pressure of 2,000 volts. The diagram (*Fig. 2*) shows the essential points of the arrangement, for particulars of which the Authors are indebted to Mr. P. V. McMahon, Assoc. M. Inst. C.E., the Company's chief engineer.

Two 500-volt dynamos in series at the power-house supply

Fig. 2.



City and South London Electric Railway.

current to the conducting or live rail in each of the tunnels. These two live rails—which are shown on the diagram for clearness as trolley-wires—form the "outers" of the 1,000-volt three-wire system. The track or running rails of both tunnels form the earthed "middle" conductor. Balancers are connected across the system at intervals as shown in the diagram, and batteries are provided at the power-house and at two other points.

So far the arrangement is simply the Hopkinson three-wire system applied to a railway. For supplying the more distant parts of the line an interesting method of utilizing a higher voltage is used. Two additional 500-volt dynamos are connected in series with the main generators, one on either side. These additional dynamos may be steam-driven, or they may be motor-generators, electrically driven by the main dynamos. Thus there are four 500-volt dynamos in series supplying high-tension feeders at a pressure of 2,000 volts. Each pair of feeders is taken to a sub-station containing two dynamos, each dynamo having two 500-volt windings on its armature. Each of these double-wound machines forms a motor-generator. For the sake of clearness two separate machines, M and G, on one shaft are shown on the diagram, instead of one machine with two armature-windings. All the four windings are connected with their electromotive forces in series. The "middle wire" (the track or running rails) is connected to the middle point of the series, and the two live rails are respectively connected between the first and second and between the third and fourth armature-windings. The current in each high-tension feeder passes through one winding on its way to the live conducting rail, losing 500 volts or half its voltage to earth. This winding acts as a motor, and causes the second winding to act as a generator, which produces a current approximately equal to the motor current, also at 500 volts. The two currents in parallel enter the live rail at a pressure of 500 volts from earth. A similar action takes place at the other machine. Thus each machine halves the pressure and doubles the current. To distinguish these machines from balancers, they are termed "reducers." As machines used in this way transmit half the energy without transformation and directly convert only the other half, they need be only half the size of ordinary continuous-current converters, and their losses are proportionately less. This method may also be applied to any two-wire 500-volt system, giving the advantages of 1,000-volt transmission for feeding distant points, which would be equivalent to one side of the City and South London system, but without balancers.

Composite Continuous-Current and Alternating-Current Systems.

With the great development of electric tramways in America on the simple 500-volt continuous-current system came a demand for transmitting the energy to the tramways by some better and cheaper way than by the enormous conductors necessary for working at this pressure. For this purpose, as with electric lighting, alternating currents offered advantages for the generation, transmission, and transformation of currents of very high voltage which were not possessed by continuous currents. By the use of rotary converters or motor-generators for turning the alternating into continuous current, the advantages of the two systems were combined, without any need for altering any part of the existing tramway equipments. This system is usually called a continuous-current system. It would perhaps prevent confusion if it were called a "composite system."

This composite system has been largely used in America for tramways, and to some extent for railways. The large overhead electric-railway system of Chicago, however, works by the simple 500-volt continuous-current system, as is the case with the much older Liverpool Overhead Railway.

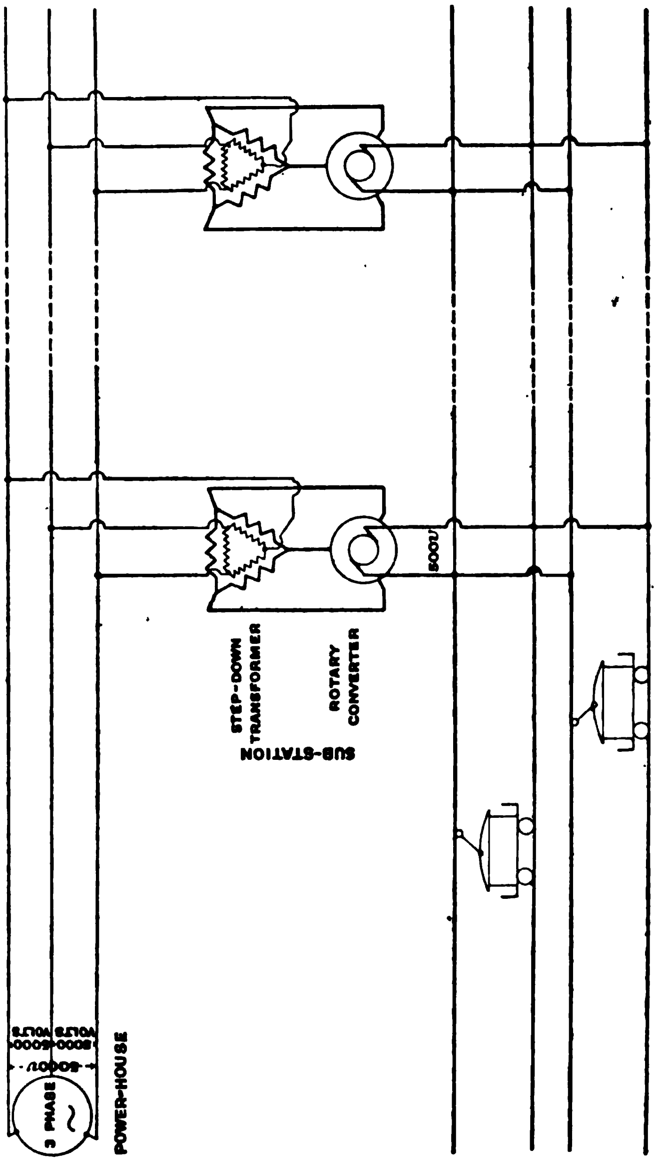
The only working example of the composite system for railways in this country is the Central London Railway, the third of the "tube" railways and the fourth of the electric railways: *Fig. 3* is a diagram of this system. High-pressure three-phase currents are produced in the generating-station. On the Central London Railway the pressure is 5,000 volts; for the Inner Circle 11,000 volts is proposed. These currents are transmitted to transforming sub-stations placed at intervals along the line, where they are transformed first to low-pressure three-phase currents by static transformers, and then to 500-volt continuous current by rotary converters. The continuous current so produced passes to the railway at each sub-station. So far as the actual railway is concerned, it is worked exactly like an ordinary 500-volt two-wire tramway or railway—at least, this is the case in all applications of the method up to the present. The difference is in the generation, transmission and transformation.

All the parts of the composite system have been worked out to a high degree of perfection. Some considerable difficulties were experienced with the connecting link, namely, the rotary converter; but these have been mostly overcome, although it is still an open question whether it is not better to use motor-generators, that is, ordinary alternating-current three-phase motors driving continuous-current dynamos. Some comparative figures are given later.

The continuous-current part of the composite system is obviously

capable of a good deal of variation. It may be a 500-volt two-wire system with one insulated conductor at 500 volts above earth, the

Fig. 3.



COMPOSITE SYSTEM (*Voltages as on the Central London Railway*).

other conductor being the rails, as on the Central London Railway; or the second or return conductor may also be insulated to avoid

earth or electrolysis trouble, which is the system approved by the Board of Trade as the result of the recent arbitration. Or again, it may be a three-wire system with 1,000 volts across the two outer insulated conductors, and the middle conductor—the rails—earthed. Or it may be any other continuous-current arrangement, such as the three-wire system used on the City and South London Railway (Appendix I.).

Alternating-Current Systems.

Three-phase Working.—In this country and in America, although three-phase alternating currents are being used for generation and transmission, the actual working of the motors on the trains is being done in all cases by continuous currents.

On the Continent, development has been carried a stage further. Three-phase alternating currents are being used, not only for generating energy and transmitting it to the trains, but also for working them. It is interesting to note that, while in America there is no evidence of any movement in this direction, engineers in Switzerland, Italy, Hungary and Germany seem to have turned aside from continuous currents for railway working, and, as a matter of ordinary practice, are giving the preference to three-phase alternating currents for both long and short lines. Some of the most difficult problems in traction are being worked out in this way. In the countries mentioned, three-phase alternating current railways may be seen either regularly at work, under construction for regular work, or in use for experimental purposes. The following Table (p. 50) gives some particulars of these lines.

The first three examples are mountain railways of short length, but with gradients of 1 in 5 and 1 in 4.

The Burgdorf-Thun railway[1] has a special interest as a full-gauge three-phase railway, forming part of the general railway system of Switzerland. The trains get their energy by a 16,000-volt transmission-line from a water-power station where the Kander river enters the Lake of Thun. This generating-station is about 4½ miles from the Thun end of the line and about 29 miles from the Burgdorf end. Part of the railway is traversed both by ordinary steam-driven trains and by trains drawn by three-phase locomotives.

The speed of the passenger trains is about twice that of the goods trains, the speeds mentioned being approximately synchronous speeds, fixed by the construction of the motors and the periodicity of the supply.

[1] Minutes of Proceedings Inst. C.E., vol. cxli. pp. 366 and 438.

THREE-PHASE ELECTRIC RAILWAYS.

Name.	Date Opened.	Length. Miles.	Gauge.	Maximum Gradient.	Speed. Miles per Hour.	Locomotives or Motor-Cars.	HP. per Train.	Periods per Second.	Trolley-Line Voltage.	Transmission Voltage.	Remarks.
Zermatt-Gorner Grat[1]	1898	5·7	Metre	Rack 1 in 5	4·35	Locomotive	180	40	540	5,400	Braking on down gradient by returning energy to line.
Jungfrau	”	2·2	”	” 1 in 4	..	”	200	38	500	7,000	Ditto.
Stansstad-Engelberg[2]	1899	14	”	Adhesion 1 in 20 Rack 1 in 4	12·5 3	Motor-Car Locomotive	105 150	40	750	5,300	About 1 mile of rack; braking on down gradient by returning energy to line.
Burgdorf-Thun	”	25	4 feet 8½ inches	1 in 40	Passenger 22·5 Goods 11·2	Motor-Car Locomotive	240 300	40	750	16,000	Generators 4,000 volts; step-up transformers.
Valtellina	..	67	”	..	Passenger 42 Goods 20	Motor-Car Locomotive	.. 600	15	3,000	20,000	"Cascade" starting and braking. Returns energy to line when braking at speeds above half speed.
Zossen (Berlin)	..	14	”	1 in 185	102	Motor-Car	3,000	50	10,000	10,000	Step-down transformers on the train. Braking by separately exciting and short-circuiting the motors and by reversing motors. Not yet open. Experimental military railway. (High speed.)

[1] Minutes of Proceedings Inst. C.E., vol. cxxxv. p. 403.

[2] *Ibid*, vol. cxxxviii. p. 558, and vol. cxxxix. p. 386.

The Table includes the military line at Zossen, on which experiments are being made at speeds of 100 miles per hour and more, with pressures of 10,000 volts supplied directly to the trains; and also the 67-mile Valtellina line[1] in Sondrio, Lombardy, of which so much has been heard in the recent arbitration. The Valtellina line is not yet working, and it is reported that the water-power is not yet available. It is the longest line, and differs from the others in having a much higher transmission-pressure; and also in the method of control, whereby the motors are arranged in "cascade" or "tandem" for accelerating and for braking. In this method, when starting, one motor of a pair has its stator or primary element connected to the line, whilst its rotor or secondary element, instead of wasting its induced current in resistances, sends it to the stator of the other motor. This arrangement can be used only up to half speed when accelerating, and down to half speed when braking. The second motor is altogether out of circuit at other times.

All these lines are three-phase; and all have two overhead trolley-lines and use the rails as the third conductor, except the Zossen line, which has three trolley-lines. The trolley-line pressure ranges from 500 volts, with transformers at intervals, to 10,000 volts without transformers. The transmission-pressure ranges from 5,300 volts to 20,000 volts. On most of the lines the motors are arranged to act as generators when going down hill or when braking, and are so enabled to return energy to the line.

Comparison of Systems.

In reviewing the whole field of electric traction, it must be recognized that there is at present no system actually working which satisfies at once the requirements of short and busy town lines, of longer suburban lines, and of still longer main lines. The present continuous-current systems, whether with or without alternating current methods of generation and transmission, do not appear to contain the elements necessary for a comprehensive general system.

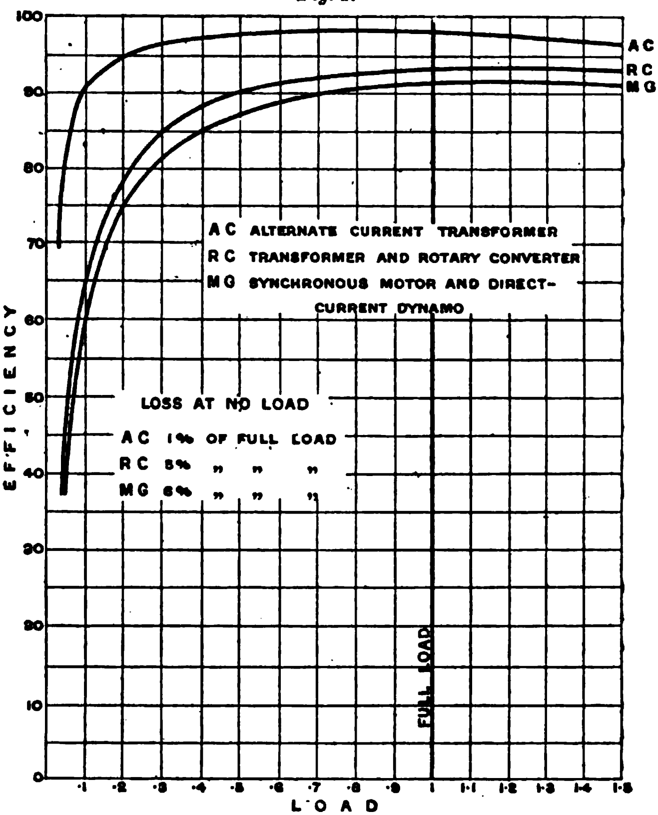
For short town lines there is no difficulty. If it is necessary to go beyond the simple 500-volt system used at Liverpool and Chicago, then the three-wire 1,000-volt system is available; and if this is not enough, there is the 2,000-volt method of feeding, as on the City and South London Railway. It is quite possible that the latter system will be found more economical, both in first cost and in working-expenses, than the Central London composite system (Appendix II.).

[1] Minutes of Proceedings Inst. C.E., vol. cxlviii. p. 439.

It remains to be seen which will prove the better for short lines; but it is clear that neither is suitable for long lines.

It will be useful to consider some of the advantages and disadvantages of the systems already described, viz.:—the continuous-current system, as exemplified in the City and South London Railway; the composite (alternating current transformed to continuous current); and the three-phase alternating-current system.

Fig. 4.



EFFICIENCIES OF SUB-STATIONS.

The composite shares with the purely alternating-current systems the great advantage of being able to use very high voltage for transmission; while the continuous-current system, assisted by high-tension continuous-current feeders, seems restricted to some such moderate voltage as the 2,000 volts used in the only example that exists, and for this reason its scope is limited to comparatively short distances.

With any purely alternating-current system the transforming arrangements are cheaper, simpler and less wasteful than the rotary converter or motor-generator of the composite system, or than any continuous-current transforming system.

The curves of efficiency of transforming-stations given in *Fig. 4* show that the transformation-losses with the alternating-current system at no load or at a small average load are about one-fifth or one-sixth of those of the composite system, while at larger loads they are about one-third or one-fourth. The efficiency of sub-stations on the City and South London Railway system may be taken as somewhere between those of the alternating-current system and the rotary-converter system.

It will be seen that in the composite system the aggregate losses on a large number of sub-stations may be very considerable. With the alternating-current system not only is the no-load loss small, but by automatic switching-gear it may be greatly reduced, which is not practicable with the rotating machinery necessary for the composite system.

The alternating-current system has the still greater advantage of dispensing with attendance at the sub-stations. It has a further advantage in the fact that the transformers for any given total power may be spread along the line, *i.e.*, there may be many small sub-stations instead of a few large ones. The distance the current has to travel along the line and along the rails may thus be reduced, and economies may be effected in the cost of the conductors and in the losses in them.

As to cost of sub-stations, the comparison is approximately as follows:—

COST OF TRANSFORMING-STATIONS.
(Pounds sterling per kilowatt.)

—	Alternating-Current System.	Composite System.	
	Transformer Sub-Station.	Rotary Converter Sub-Station.	Motor Generator Sub-Station.
Transformers	£1·8	£1·9	None
Rotary converters	None	4·8	None
Synchronous motors	None	None	£4·7
Continuous-current generator . .	None	None	5·7
Switch-gear, starting-gear, connections, etc.	1·3	4·0	3·3
Building	0·6	1·8	1·5
Total per kilowatt .	£3·7	12·5	15·2

The above figures include a fair proportion of spare plant in each case.

Accumulators.—Both the composite and the continuous-current systems have the advantage over the alternating-current systems that they may easily use accumulators. There is an increasing tendency to use accumulators for traction. They reduce the "peaks" at times of momentary heavy loads, thus equalizing the load on the generating-station, and lessening the amount of running plant necessary. If distributed on the line or placed at a distance from the generating-station, they help to keep the pressure uniform and to reduce the need for feeders. They can deal with light traffic when the station is shut down. The arrangements of Mr. J. S. Highfield, whereby both charging and discharging are facilitated by special boosters, will probably increase greatly their usefulness, especially for meeting momentary heavy demands.

Batteries may, however, be used with alternating-current systems, although not as easily as with continuous-current or composite systems. The charging of accumulators on an alternating-current system involves precisely the same process as the ordinary transformation of alternating-current to continuous-current in the composite system; and the discharging involves simply an inversion of that process. An alternating-current motor, driven from the alternating-current system, may drive a continuous-current dynamo charging the battery. When discharging, the battery drives the continuous-current dynamo as a motor, and this drives the alternating-current motor as a generator, feeding back on the alternating-current line. The alternating-current motor may be either synchronous or non-synchronous, or may even be a rotary converter. With none of these is there any difficulty, if the object is merely to furnish a supply for a short time when the generators are shut down.

For helping momentary loads, however, whatever system is adopted must be automatic in its action, in order to meet the rapid and large fluctuations in the load. In this respect the method of using batteries for railway work must differ from methods suitable for lighting. Although the problem thus presented is more difficult with alternating than with continuous currents, it will not be found insoluble if it prove to be worth while to use accumulators for this purpose.

Compared with composite or continuous-current systems, multiphase systems are at a disadvantage in requiring the use of at least two live conductors, instead of one. This difference increases the complication and cost of the overhead construction, and the risk of interruption by short circuits; and these matters become more

and more serious in proportion to the complexity of the junctions, shunting-yards, etc.

With multiphase systems the synchronous speed of the motors, corresponding with a definite speed of the train, cannot be exceeded; therefore lost time cannot be made up. This may be of importance to main-line railways. But, although it is true that the synchronous speed cannot be exceeded, it is not quite accurate to say that the full speed is fixed by the conditions of synchronism. As a matter of fact, between the full speed of a heavy train and that of a light one there is a difference represented by the "slip" of the motors. Thus a light train will gradually overtake a heavy one.

Continuous-current or composite systems are more flexible in respect of speed, although it is not advisable to run for more than a short time with the ordinary series-parallel arrangement, except at half or full speed; for at intermediate speeds wasteful resistances have to be inserted in the circuit. Nor is it advisable to run at more than the full normal speed in order to make up time, as this can be done only by weakening the field-excitation, with some risk of commutator-troubles. These remarks apply to series motors as usually arranged. It is reported from the Continent that the latter difficulty has been avoided in some large traction-motors by recourse to the old device of commutating poles.

Small variations of voltage do not seriously affect the maximum speed of alternating-current motors for any given load. With continuous-current motors the maximum speed for any given load is approximately proportional to the voltage of supply. With large variations of voltage, however, the effect with continuous current is different from that with alternating current. Continuous current has a decided advantage in this respect. However low the voltage may fall, continuous-current motors can develop a large torque, even if they cannot attain a high speed; with alternating-current induction motors, on the contrary, a considerable fall of voltage would prevent the motors from working at all. Fortunately for the future of alternating-current working, the pressure is more easily kept up than with continuous current.

The disadvantage of the composite system is the necessity for sub-stations at frequent intervals, equipped with running machinery which requires skilled attendants. Such machinery comprises static transformers and rotary converters; or motor-generators, high- and low-pressure switch-gear, and usually electric motors and fans for ventilating and cooling the apparatus, as well as motors for starting the converters. All this machinery, with its proper proportion of reserve, involves heavy capital expenditure, and large working-

expenses in power, attendance and maintenance. For short and busy lines, such as the Central London Railway, these burdens may not be too serious; but for longer lines with less frequent trains—main lines or even suburban lines 20 miles to 50 miles in length—it will probably be found that the working-expenses under this system will be too heavy to enable it to compete successfully with the steam-locomotive.

Before considering the requirements which seem desirable for a comprehensive system, attention may be directed to several matters of general importance.

Starting-Torque of Alternating-Current Motors.

Not many years ago alternating-current motors were inferior to continuous-current motors in their starting-torque. On the other hand, they possess some advantage in not having any commutators; and for transmission they have the further advantage that for high pressures they may be used much more conveniently than continuous-current motors. In large sizes they are easily made to work at very high pressures; and in small sizes they can be worked from high-pressure transmission lines by step-down transformers.

The development of multiphase motors has practically put continuous-current and alternating-current motors on an equal footing in regard to starting-torque. With single-phase motors, however, the starting difficulty has not yet been so successfully solved.

Of the two practical types of single-phase motors, viz., the synchronous motor and the non-synchronous induction motor, the former requires to be started from rest and run up to full speed by some auxiliary means. When got up to synchronous speed it is an excellent motor, running of course with absolute regularity, or at least following exactly the speed of the machine by which it is driven. The synchronous motor has a valuable quality not possessed by the induction motor. It usually has a high power-factor; that is to say, the idle current that it takes is very small, and by suitable variations of its field-excitation it may be made to compensate either for the capacity or for the self-induction of the circuit. By this means it is possible on long lines to keep the power-factor higher t an with induction motors.

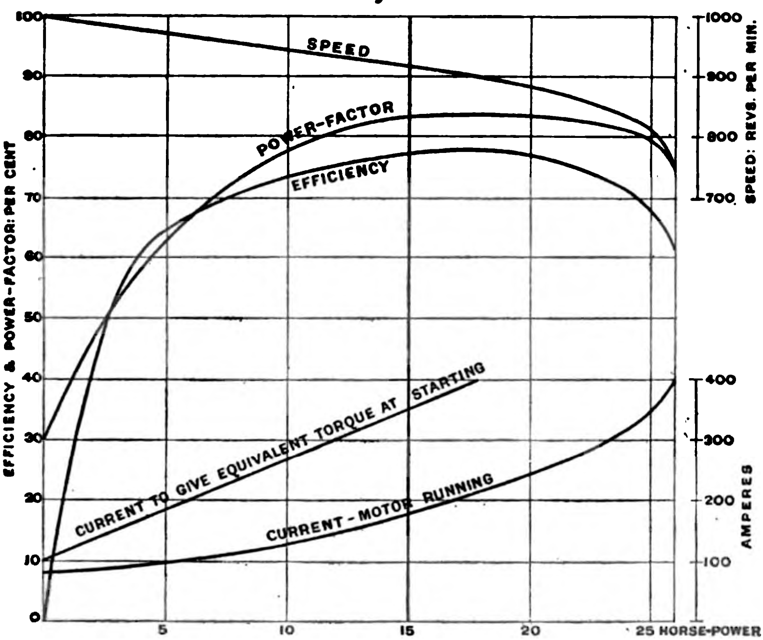
Single-phase induction motors have recently been considerably improved in their starting quality, but at some sacrifice of efficiency. Up to 2 or 3 years ago it was necessary to start them on a loose pulley, or at least without any load, as their starting-torque usually did not exceed one-fifth of their full-load torque; in fact, it was not always possible to get such motors to start from

rest without some slight assistance, although when started and run up to speed they were fairly satisfactory.

Recent improvements have been made in this respect, however, especially by Mr. A. Heyland, whose motors now, when required, are made to start with full-load torque, or even with slightly more.

A curve is given (*Fig.* 5) showing the various qualities of such a motor. It will be seen that the efficiency is not so high as with good continuous-current motors; but for many purposes such a single-phase induction motor will do all that is required of it.

Fig. 5.



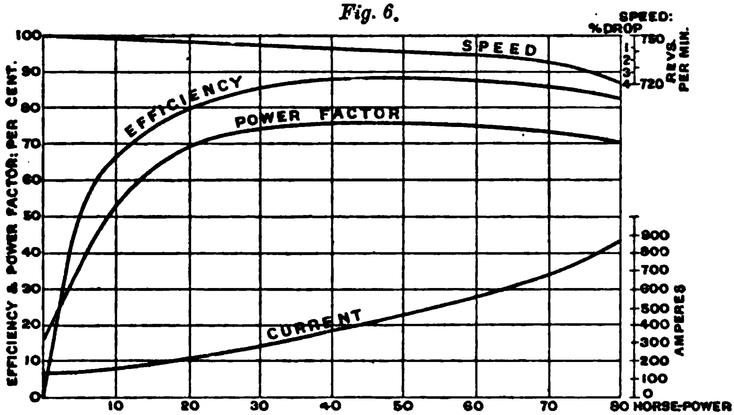
CHARACTERISTIC CURVES OF 15 HP. SINGLE-PHASE INDUCTION MOTOR. 50∼ 100 VOLTS (*Heyland*).

It starts at full-load torque with about twice the normal full-load current. The "slip," or fall of speed from no load to full load, is about 8¼ per cent. It will do about two-thirds more than its full load with a drop in speed of about 20 per cent. Its efficiency at full load is about 76 per cent., at half-load about 70 per cent., and at quarter-load about 60 per cent. Its power-factor is about 0·83 at full load, 0·72 at half-load, and 0·57 at quarter-load. These results are for a 15-HP. motor. It is not as good as either a continuous-current motor or a multiphase motor of similar output.

It is given here in order to show the results now obtainable when a single-phase motor is designed for full starting-torque. Probably better results can be attained in larger sizes.

When large starting-torque is not required, single-phase motors are made with higher efficiency, larger power-factor and small slip. *Fig. 6* shows the characteristics of such a motor of 50 HP.,

Fig. 6.



CHARACTERISTIC CURVES OF 50 HP. SINGLE-PHASE INDUCTION MOTOR.
50~ 120 VOLTS (*Brown, Boveri & Co.*).

made by Messrs. Brown, Boveri & Co. *Fig. 7* illustrates the starting-torque of a continuous-current series motor and of three-phase and single-phase alternating-current motors.

APPARENT RESISTANCE OF RAILS WITH ALTERNATING CURRENT.

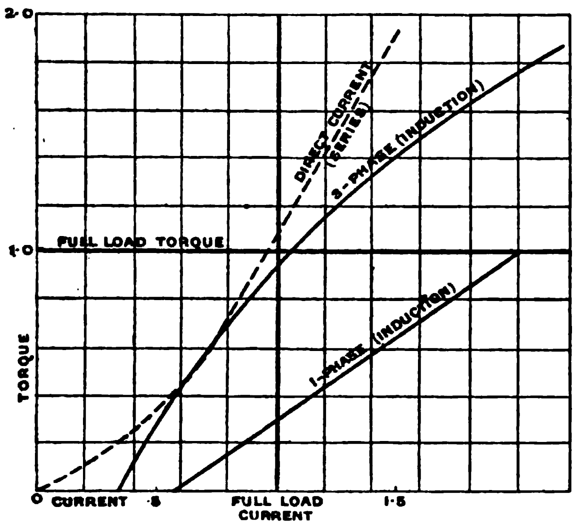
A very important matter in connection with alternating-current railway working is the resistance offered by the rails when they are used for the purpose of carrying current. With continuous currents the problem is a simple one; the resistances of the rails are well known.

It is usually found in practice that a line of rails has about ten times the resistance of copper of equal cross-sectional area. The ratio, however, varies considerably with the composition of the rails, and with the degree to which they are insulated from the surrounding ground. This ratio of 10 : 1 is somewhat higher than the ratio of the specific resistances of the two metals, and it includes a certain amount of extra resistance due to the bonds or joints. With alternating currents, however, the "skin effect" has to be considered, which, in large conductors, causes the apparent resist-

ance to be greater than with continuous currents. The reason for this is that the alternating current is not conducted uniformly by the whole section of the metal, but is denser on the outside than inside. With copper conductors and ordinary periodicities the skin effect is not serious; in solid rods up to nearly 1 inch in diameter it is quite small. In flat or ribbed copper conductors ½ inch or so in thickness, or in tubes of a similar thickness of copper, it is also unimportant; but in iron the condition is complicated by the varying magnetism set up by the alternating current, whereby the skin effect is intensified.

On the Burgdorf-Thun line, Mr. C. E. L. Brown has kindly

Fig. 7.



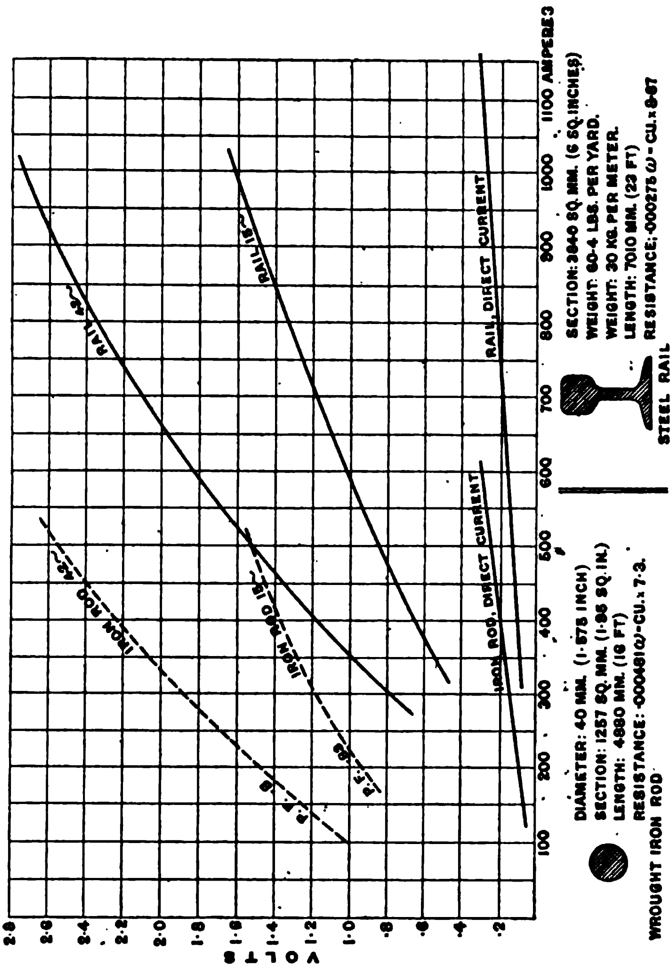
STARTING-TORQUE OF MOTORS.

informed one of the Authors, some measurements have been made which show that the apparent resistance of the rails is equal to about eight times the ohmic resistance, and that the ohmic resistance is about nine times that of copper; on this basis the resistance is about seventy-two times that of an equal section of copper. But this increase of apparent resistance depends upon the amount of current and upon the periodicity. On the Burgdorf-Thun line the periodicity is about 40 cycles per second; the Authors do not know at what current-density Mr. Brown's tests were made.

The Authors have to thank Mr. Blathy for sending them a diagram (*Fig. 8*) giving results of tests at 15 and at 42 periods

per second on a round wrought-iron rod and on steel rails, the dimensions of which are given at the foot of the diagram. The curves show the voltage required to send various currents through the conductors. At the lower part of the diagram

Fig. 8.



WROUGHT-IRON ROD AND STEEL RAIL. APPARENT RESISTANCE WITH ALTERNATING CURRENT (*Blathy*).

the results are given with continuous current for comparison. The voltage with alternating current is much higher than with continuous current, and is nearly twice as great at 42 periods per second as at 15 periods. The alternating-current curves are not straight. With high current-densities they bend over in the manner of

magnetization curves, and probably for a similar reason. The observations do not carry the curves down to zero, but from their form it is probable that near the origin also they resemble magnetization curves. The extra drop with alternating current does not all indicate lost energy. Mr. Blathy's diagram gives the power-factor (P. F.) observed in his tests of the iron rod, showing that only 80 or 82 per cent. of the observed drop represents energy actually lost in the rod; and it may be assumed, though it is not stated, that a somewhat similar figure would hold for the steel rail.

It is evident from these results that the rail-return question with alternating currents requires careful study. It has always been a difficult question with continuous currents: in some ways it appears likely to be still more difficult with alternating currents.

It may be useful to consider what is involved by the effect of this rail-resistance, and to compare results with continuous current and alternating current, so far as it is possible to do so from the information available, and within the limits of a section of this Paper.

In continuous-current railways and tramways the drop of pressure in uninsulated rail-returns is now restricted by the Board-of-Trade rule to a maximum of 7 volts, or about 1·4 per cent. of the working-pressure; this limit being imposed mainly to prevent electrolytic action on gas- and water-pipes by continuous current. Were it not for this limit, a much larger drop might be used; for example, such a drop as is customary in the live line, viz., about 50 volts or 10 per cent. With alternating currents there is practically no electrolytic action, unless the current-density is very high; a much larger drop than 7 volts might therefore be allowed, if it were not for interference with telephone and telegraph lines.

The Table at p. 62 is deduced from Mr. Blathy's curves. It has been compiled for a single track using two 90-lb. rails as the return conductor. It gives the drop in voltage per mile, and the distance in yards at which the 7-volt Board-of-Trade limit is reached with various currents, both continuous and alternating —the latter at 15 and at 42 periods per second. This Table must be taken only as indicating approximately what will occur. In the first place it will be seen that the curves do not go down to very low current-densities, and it has been necessary to extend them towards zero; the form of this extension within the limits of the Table, however, is not open to much doubt. To bring the Table into accord with probable railway conditions, 90-lb. rails are taken, instead of the 60-lb. rails of the diagram, and the assumption is made that with alternating currents

LOSS OF VOLTAGE IN RAIL-RETURN.

Total Current in Two 90-lb. Rails. Amperes.	Amperes per Square Inch.	Volts per Mile.			Yards for 7 Volts.		
		Continuous Current.	Alternating Current.		Continuous Current.	Alternating Current.	
			15~	42~		15~	42~
1,000	56·5	21	120	210	585	103	59
900	50·8	19	101	176	650	122	70
800	45·2	16	85	147	730	145	84
700	39·5	14	66	112	835	185	110
600	33·9	12	53	87	972	233	141
500	28·2	11	39	67	1,160	318	185
400	22·6	8	28	50	1,460	446	244
300	16·9	6	21	34	1,950	597	358

for the same current-density the drop for a given distance will be the same in the large as in the small rail. This can only be considered as approximately true. Further, no allowance has been made for joints. There is some uncertainty as to what conductivity can be relied on with existing methods of bonding. Sometimes the bonded rail-joints may add as much as 20 per cent. to the total resistance. For some modes of bonding, however, it is claimed that the joint is so good that it adds nothing to the total resistance. The Table shows the conditions for the 7-volt limit, neglecting or eliminating resistance of joints.

With continuous currents the 7-volt limit is reached in 1 mile with 330 amperes, or 165 kilowatts at 500 volts. With alternating currents at 42 periods, 300 amperes give 34 volts per mile; at 15 periods the drop is 21 volts. The drop is not directly proportional to the current, otherwise 62 amperes would give 7 volts at 42 periods. At the lower currents, however, the probable form of the curve shows that a drop of 7 volts would be reached with about 100 amperes at 42 periods.

The increased resistance with alternating currents is a serious effect, and would be still more serious if it were not for the fact that with alternating-current distribution it is possible to put the transformer sub-stations nearer together without increasing the working-expenses, because constant attendance is not necessary. Hence the current need never have to travel any great distance along the

rails. Moreover, alternating-current methods of working enable much smaller currents to be used than are necessary for direct-current methods, because with alternating currents much higher pressures can be used for distributing the power to the trains.

It is probable that, as alternating-current methods become developed, this effect will lead to two changes from present continuous-current practice. In the first place an insulated return-conductor on the track is likely to be used, instead of the uninsulated rails. Such a return conductor will be earthed at one point: that is to say, it will be at earth potential, except for the voltage due to its own drop. It could hardly be regarded as a live conductor. There is much to be said for this course, even with continuous currents. It saves bonding of the rails, and allows as large a drop on the return as conditions of efficiency render advisable. As far as efficiency is concerned, the drop in an insulated return-rail might be several times the amount allowed by the Board of Trade.

The second probable change will be the use of copper instead of iron for the return conductor. Iron or steel is now used for insulated track-conductors for two reasons: it is cheaper, and it is stronger and more rigid. On all but very short lines, however, it is found necessary to supplement the rail conductor—whether it be the live iron rails or the uninsulated iron rails—by insulated copper feeders. With alternating currents it will only be necessary to carry out this plan more freely; either by using an insulated copper return-rail—possibly with a wearing surface of iron—or, if iron is necessary for rigidity, a copper conductor connected at frequent intervals to an iron rail.

In the relative cost of steel or iron and of copper there is now a less disproportion than might be supposed, even for continuous-current working. Taking the resistance of steel rails as ten times that of copper of equal section, and allowing for the specific gravity of copper being about 14 per cent. higher, the two metals become equal in cost, as electrical conductors for continuous current, when copper is 8·8 times the price of iron. The actual market prices at present are—steel rails about £5 10*s.* per ton, electrolytic copper about £66 per ton, or 11·5 times the price of iron. This comparison concerns continuous-current conductors alone; it must be taken as only approximately correct, because the ohmic resistance of the rails varies a good deal with the quality, and the prices of both metals vary from time to time; but it shows that, on the bases stated, copper is about 31 per cent. more costly than iron.

With alternating currents, however, the balance is greatly in

favour of copper; at least, within the range of the curves and Table. For example, the lowest figure in the Table shows that the apparent resistance of iron, at 15 periods per second and at the low density of about 17 amperes per square inch, is about three times the ohmic resistance. Under these conditions iron is about 2·3 times as dear as copper. At the highest value in the Table (viz., at 42 periods per second and 56·5 amperes per square inch) the apparent resistance is ten times the ohmic resistance. Under these conditions iron is 7·7 times as dear as copper. It is safe therefore to say that with alternating currents the balance will be in favour of copper under any conditions, except possibly at current-densities so low as to be hardly practicable.

There will be a drop due to self-induction, even when copper is used instead of iron; but as the phase of the back electromotive force of self-induction is at right-angles to the impressed electromotive force, it will generally cause but a small additional drop of voltage.

In continuous-current working, rail-drop is minimised by feeders, assisted in some cases by negative boosters on the plan originally proposed by Mr. Gisbert Kapp, M. Inst. C.E. A similar plan may be used with alternating current, by means of a static transformer, having its primary across the mains and its secondary arranged to add volts to one or more return feeders. This, however, would not be self-regulating. A static transformer may, however, be arranged as a self-regulating booster, for which purpose it should have two windings, one in series with the out-going feeder, the other in series with the return feeder. It would then add volts to the latter proportionately to the current, but would do so at the cost of a reduction of pressure in the out-going feeder. Or a self-regulating effect could be secured by a rotating booster, consisting of a small alternator synchronously driven and having its field compounded by re-dressed current from the out-going feeder. The return feeder would be passed through the armature, the voltage rising with the current.

Periodicity.

From the examples given in the Table of alternating-current railway systems (p. 50) it will be seen that, except on the Valtellina line, the periodicity is not very low, that is to say, it is between 38 and 50 cycles per second. This has no doubt been so arranged in order to enable lighting as well as the traction of the trains to be effected directly by the alternating current. On the Valtellina line the low periodicity of 15 cycles per second seems to have been

adopted to enable direct-coupled motors to be used having few poles. With the proposal to adopt geared motors, this necessity no longer existed, and it is understood that Messrs. Ganz and Co. proposed to use 25 periods on the Inner Circle, which is the periodicity now used on the Central London Railway, and is also proposed for the alternating-current working on the Inner Circle.

It may be that in some cases the considerations affecting the rail-return will prove the governing factor in the choice of periodicity with alternating-current working of trains: that the advantage of a low periodicity in this connection will more than counter-balance the disadvantage as regards lighting. For the composite system, a low rate is used because high-frequency rotary converters do not work satisfactorily.

Where the lighting is important, probably a lower periodicity than 40 cycles per second will not be used. It is significant that, in some of the more recent transmission projects, periodicities suitable for lighting as well as for power are being used.

In connection with electrostatic capacity, a high frequency is objectionable on account of increased loss from dielectric hysteresis; but it is favourable as regards the ability of the cables to counteract self-induction, and so to raise the power-factor. Condensers are coming into use largely for this latter purpose. Their effectiveness is directly proportional to the periodicity.

Lighting.

On all underground lines, the electric lighting of stations, lifts, and tunnels, should be on a circuit entirely separate from the circuit supplying energy to the trains. Interruption of the main supply should not interfere with the lighting.

On trains, separate provision may be made, either by a separate conducting line, or by a small dynamo or motor-generator on the train, arranged in conjunction with accumulators, so as to ensure a certain number of lamps being kept going. If this is not done, a number of oil or other lamps should always be kept alight.

On main lines there is now little difficulty in getting a cheap supply of electrical energy locally for station-lighting; or, failing this, motor-generators and accumulators are available, supplied from the traction-mains.

With alternating current there is a great advantage in using periodicities of between 40 and 50, inasmuch as these enable all lighting to be done by the alternating current transformed by static transformers to any desired pressure, without any necessity for rotary transformers. It is probably for this reason that the

Continental lines have in most cases adopted 40 to 50 periods per second. Messrs. Ganz and Co. state that, by using three-phase lamps at very low periodicities, they are able to get a fairly satisfactory light. The lamps have three filaments, one in each phase, and the flicker, which would be objectionable with a single filament, becomes equalized when the three flickers overlap one another: but the arrangement is not a good one.

Return of Energy to the Line.

More than twenty years have elapsed since Sir William Siemens pointed out[1] that, if two trains were driven electrically by a common source of energy, a train descending a hill would help an ascending train almost as if they were connected by a rope or chain. Till recent years little practical use has been made of the principle underlying this observation, namely, that a motor when driven by a train can be made to act as a generator and send current back to the line. Attempts have been made to utilize this property on continuous-current systems, but not with any marked success.

Some years ago Mr. Frank Sprague, M. Inst. C.E., attempted to introduce a system in which shunt motors were used, and energy was returned to the line during braking or coasting; but nothing came of it. With ordinary shunt motors the range of speed through which such an action is possible is small. When attempts are made to increase the range by using compound motors, complication becomes excessive. With series motors, such as are now always used for tramways or railways, the difficulty is greater still.

Although various arrangements have been proposed for returning energy to the line, they do not seem to have come to anything, so far as continuous currents are concerned. On long level lines where the braking periods are short relatively to the whole length of the run, it is obvious that little advantage can be gained by returning power. With lines on which the stoppages are frequent, it may be worth while to make use of the energy of the train in this way. One simple way of using the energy of the moving train—involving nothing electrical—is that adopted on the Central London Railway, where most of the stations are at the top of an incline. The energy is stored in the train when driving itself up the incline to the station; and is returned again, assisting the acceleration of the train, when descending the incline from each station.

[1] Journal of the Society of Telegraph Engineers, vol. ix. p. 301.

With the introduction of three-phase alternating-current, attempts to return energy to the line have been revived, as it is easier to return it by alternating-current motors than by continuous-current motors. The Table of the existing three-phase lines (p. 50) shows where this method is used. On those lines it is done not so much for the sake of economy as because it provides a convenient controllable brake for descending steep gradients. On some lines for which water-power is used, economy is quite a secondary consideration. In fact, where there are few trains running, there may be no ascending train to take the power returned to the line by the descending train. In using this as a braking method, therefore, it is necessary to make sure that there is some means of disposing of the returned energy. It may be dissipated by a resistance carried on the train or in connection with the line. On the Engelberg line a water-resistance is connected across the line at the power-house for the purpose. On the Gorner-Grat line a similar arrangement is used. In the event of there being no ascending train, the descending train drives the generating-station. When the turbines have reached a certain increased speed, a resistance is put across the line, which absorbs the incoming energy. It is a pretty sight to see these trains coming down 1-in-5 gradients braked in this way.

The action may be explained thus:—The three-phase induction motors at light load run practically synchronously. As the load increases, they fall below synchronism by a small amount; this is called the "slip," and is a small percentage of the synchronous speed. If such motors are driven above synchronous speed, they become generators, giving power approximately equal to that which, as motors, they would take at the same percentage below synchronous speed. In this way the motor can be made to exert its full torque as a brake when it is being driven by the train at a speed only 4 or 5 per cent. above its normal speed when working as a motor fully loaded. Trains driven by continuous-current shunt motors and those driven by alternating-current induction-motors have a power of self-control somewhat similar, except that the control is more marked in alternating-current motors, because the variation of speed necessary to change from the condition of fully-loaded motor to that of generator is smaller.

Variable-Ratio Control.

Constant-voltage is the only practical mode of supply, whatever system is used. For large starting-torque, large current is necessary, but not high voltage or large power. The saving of

power at starting is important, not only because of the cost of the energy, but also because the saving reduces the plant necessary to meet momentary heavy demands. Some variable-ratio process is wanted, by which at starting a small current may be taken at full voltage and converted into a large current at low voltage, if possible, without involving the use of wasteful resistances. Such a process would reduce the "peaks" in the output curve, lessen the amount of generating-plant required, prevent large fluctuations in the pressure of the supply, and save energy. Efficient starting is relatively of less moment on long than on short lines; but on all it is important.

At present there is no good variable-ratio process in use. The continuous-current series-parallel with two motors is at best a 2 to 1 ratio process, and does not avoid the use of wasteful resistances absorbing about two-thirds of the energy at starting. The multiphase "cascade" arrangement is also a 2 to 1 process, with the disadvantage that half the motors are idle after half-speed has been attained. In the ordinary multiphase system the motors are simply in parallel, and do not form a variable-ratio arrangement at all.

A variable-ratio process would not only effect economies at starting; it would have advantages in regulating speed, and possibly would enable energy to be returned to the line through a considerable range of speed. The need for such a process may be judged from the fact that in present methods the maximum loss occurs with minimum useful power. The greatest output of the station, the greatest losses in the line, in the motors, and in the resistances, all occur when the least horse-power is being exerted by the train-motors—namely, at the moment of starting.

Requirements for a General System.

Having considered the systems available, the requirements for railway working may now be examined under different heads.

First as to the generation of the power and its distribution to trains on a railway, for the equipment of the line the more important requirements are as follows:—

(1) For main lines current must be supplied at extra high voltage for feeding the sub-stations placed along the line.

(2) These sub-stations must not contain any moving machinery, so that there need be no constant attendance or supervision.

(3) For main lines, or for lines more than about 50 miles in length, which run into the country, some form of high-pressure

or extra high-pressure supply must be adopted for distributing the power from the sub-stations to the trains.

(4) With a high-pressure distributing-system, overhead conductors must be used in order to make them inaccessible.

(5) The overhead distributing-system should admit of unlimited extension, and be such as could be adopted as a standard by all railways; for it is nearly as important that the overhead equipment should be the same on all railways as it is that they should all have the same rail-gauge.

(6) The overhead distributing-system should be able to supply energy to trains with different kinds of motors and different systems of controlling them.

Considering next the equipment of the trains, the more important requirements are:—

(7) A high acceleration must be possible when starting the train.

(8) On a falling gradient, or when stopping, the energy of the moving train should, if possible, be returned to the line.

(9) It should be possible to vary the speed economically within wide ranges in order to admit of running with the same train-equipment on suburban lines and on main lines: and so as to enable lost time to be made up.

(10) The motors should form, or should be combined with, a variable-ratio arrangement for starting, for speed-regulation, and for returning energy.

(11) It should be possible either to have all the motors on a locomotive, or to distribute them throughout the train.

(12) The train-equipment and control should admit of unlimited extension, and should be capable of modification so as to work with other distributing-systems than its own.

What limitations do the foregoing conditions impose?

Examining them in order, the first five lead to the following conclusions:—

(1) In order to transmit the current at extra high voltage, the generators in the power-station must be alternators, generating single-phase or multiphase alternating currents.

(2) To do without moving machinery at the sub-stations, static transformers only can be used there; and the power must therefore be distributed from the sub-stations as single-phase or multiphase alternating currents.

(3) Distribution of power to the trains at high or extra-high pressure can be effected only by alternating currents, either single-phase or multiphase.

(4) With overhead conductors, two at least must be used for three-phase currents, but one only is required for single-phase. A distributing-system which uses a single overhead conductor has such immense advantages over a system requiring two or more overhead conductors that it should certainly be adopted if possible. The advantages are the simplicity of construction and working, with the absence of insulated crossings and with freedom from the dangers of short circuits.

(5) A single-phase overhead conductor, on account of its safety and simplicity, would best admit of unlimited extension and of adoption as a standard by all railways.

The selection is thus brought down by a process of elimination to a single-phase alternating-current system for the generation, transmission and distribution of the power, with one overhead conductor, and a return conductor on the ground, which can be either the rails or an insulated conductor, at practically the earth's potential.

Single-Phase Alternating-Current Working.

Before dealing with the remainder of the requirements consideration must be given to the means by which a single-phase system can be used for driving the trains.

At present there is no example of a single-phase railway or tramway, but such a system is possible, and should be included in any account of practicable methods in view of the great advantages which it would possess were it fully carried out. From what has been said as to the starting-torque of single-phase motors, it will be evident that, at present at least, railways can be worked by such motors only if they are started without any heavy load on them. They must therefore be started independently of the train, and some means must be found for starting and driving the train by coupling the running motors to it. For this purpose it is clear a variable-ratio coupling must be used. Any arrangement of mechanical clutches for such a purpose would present great, if not insuperable, mechanical difficulties. Magnetic clutches offer a better prospect of success, if efficiency is not of primary importance. For example, a laminated multipolar magnet carried by the alternating-current motor, and another attached or geared to the axle of a driving-wheel, might be used: or two such clutches, with poles arranged to break joint. There would be a small air-gap between the polar surfaces. By varying the excitation of such a clutch, a difference of speed between the two

parts would be possible. At starting, and when the two portions were going at different speeds, the loss would be proportional to the difference of speed; it would be due to magnetic hysteresis and to eddy-currents. When full or synchronous speed of the poles was reached the loss would almost entirely cease. An exciter driven by the single-phase motor would be necessary. The whole control could be effected by adjustment of the exciting circuit of the clutch.

An electrical method of solving this problem has been proposed by Mr. Ward Leonard.[1] It presents many features of great interest, and in the Authors' opinion it is well worth careful consideration. Although it has some serious disadvantages, it appears to possess more of the essentials of a comprehensive system than any other method known. No perfect general system is ever likely to be devised; it remains to be seen whether the one under consideration affords a reasonable and practicable solution of the problem. It has been used for lifts and other purposes, but, so far as the Authors know, it has not been used for railways. It has many incidental advantages which do not seem to have been recognised.

The arrangement is illustrated diagrammatically by *Fig. 9*, which differs from Mr. Leonard's only in showing a single-phase self-starting induction-motor, instead of a synchronous non-starting motor; in principle it is the same. Its main feature is a motor-generator on the train, transforming from alternating to continuous current. A single overhead conductor is supplied with single-phase alternating current at any suitable pressure. If the distance is great or the power large, the primary mains might be at extra high-pressure, static transformers being placed at intervals for transforming down to a lower voltage.[2] One such transformer is shown in the diagram. The alternating current passes through the induction motor, and returns to the generating-station or to the transformer either by the rails or by another conductor, insulated or not. The motor is coupled to and drives a continuous-current dynamo, which in its turn supplies current to the continuous-current motor or motors driving the train. A small exciter is also driven by the induction motor, and is used to excite the dynamo

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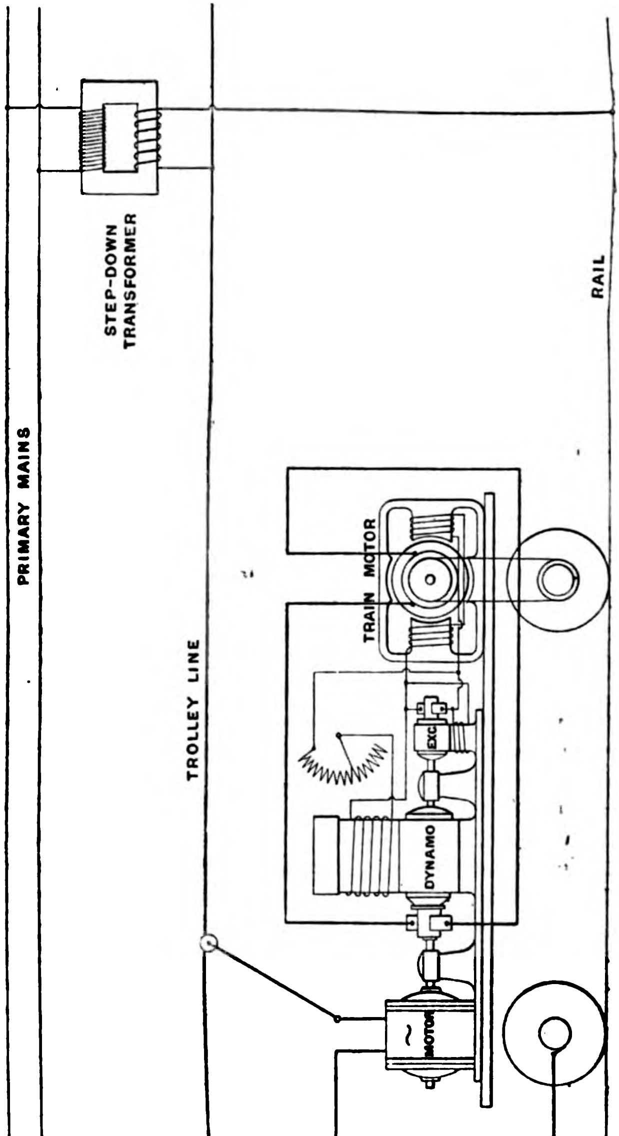
[1] British patent 14,509 of 1891.

[2] These transforming-stations will be simpler, cheaper and more compact than those in the three-phase system, inasmuch as the transformer will not require to be made up of three smaller transformers; the switch-gear and connections will similarly be simplified.

and the train-motor: it may also be used for lighting and heating the train, although the alternating current would be equally

Fig. 9.



SINGLE-PHASE VARIABLE-RATIO SYSTEM (*Ward Leonard*).

available for these purposes by the use of step-down transformers. An air-compressor for the brakes might also be driven by the

motor, either direct or otherwise. The motor-generator can be started with no load on it, just before the train has to be started. For short stops it can be kept running; and for longer stops it can be shut down and started again when wanted.

This apparently complicated system is in reality a fairly simple one. But some complication is allowable, since the system forms a variable-ratio transforming and driving gear of elastic qualities and long range. One interesting feature is that the complete control of the train is possible without any appreciable loss in external resistance. This result is attained by varying the excitation of the dynamo by means of the small resistance in its field-circuit. At starting, the train-motor requires a large current at low pressure, which is obtained by adjusting the field of the dynamo so that the voltage is just enough. There is no need for any starting- or other resistance in the motor-circuit. Then, as the speed rises, the excitation of the dynamo is gradually raised, until at full speed it is giving its full voltage and sending its full current through the train-motor against the full back electromotive force of the latter. When slowing down, or when varying the speed, the voltage of the dynamo is adjusted to supply the proper current to the train-motor without the insertion of resistances. Energy can be returned to the line when running down an incline or when braking, and at practically any speed of the train. This is done by reducing the excitation of the dynamo until its electromotive force is less than that of the train-motor. The same thing can be done by increasing the excitation of the train-motor (if it is separately excited, as shown in *Fig. 9*); or the fields of both dynamo and train-motor can be adjusted until the train-motor becomes the generator and drives back to the dynamo, which mechanically drives the alternating-current motor at slightly above synchronous speed, and so returns energy to the line. To reverse the direction of driving, the field of either the dynamo or the train-motor can be reversed. All the operations of starting, stopping, reversing, braking, and returning energy to the line, are done by adjustment of the field-excitation alone.

This variable-ratio gear is completely reversible, acting in either direction. Thus it gives large torque at low speed for starting, taking a small current at high voltage from the line, and transforming it into a large current at low voltage for the motor. It gives large reversed torque at low speed when braking, returning to the line a small current at high voltage, transformed from the large current and low voltage of the motor (now a generator). It gives either large or small torque at any speed from the lowest

to the highest, being always reversible; and it gives, what no other system gives, a relatively high efficiency at low speeds.

In this system there need be no irregularities of control or of speed, such as are caused by the "notches" in the ordinary series-parallel controller. A perfectly smooth transition can be obtained through the whole range, from large torque at starting and at low speeds, through all the variations of speed, to large power returned at stopping or braking.

A possible objection in detail to this system is in connection with the commutator of the continuous-current dynamo. The collection of the large current may be difficult in the weak field necessary to give the low voltage at starting. The reaction and sparking tendency will then be greater; but it is now known that dynamos may be made to collect quite well with practically no field at all.

The no-load losses, or the losses when the train is standing, are confined to the power necessary for driving the single-phase motor and the exciter unloaded, including their friction and that of the main dynamo. At low speeds of the trains the dynamo will work with very low pressure, very low excitation, and comparatively small losses. The motor-generator runs at or near its maximum speed, and is therefore always capable of a considerable fly-wheel effort. It should probably be considerably over-loaded during the last part of the acceleration of the train, as the over-load lasts only a short time. The motor-generator can in this way be made to work at normal full load and highest efficiency when running the train at full speed and under normal conditions, but not accelerating.

The voltage of the line and of the motor may be selected according to the conditions, as the single-phase motor may be made for almost any practical pressure—at least for sizes such as would be wanted for railways.

The alternating-current motors automatically take from the line enough energy to enable them to do the work that is at any moment imposed on them; no control is necessary so far as the alternating-current part of the system is concerned.

With this single-phase induction-motor arrangement, using motors that are now available, there is no difficulty in starting the motors, nor is there anything to fear from their not keeping up to speed. Momentary interruptions of the circuit would not cause them to slow down to rest, as would be the case with synchronous motors. The latter, however, have the advantage of a higher power-factor and a higher efficiency, and it might on that

account be found desirable to adopt them, using a small induction motor for running them up to synchronous speed.

The drawback to this system is that there is so much machinery to be carried. Besides its motors, the train must carry continuous-current plant sufficient to drive these motors, and alternating-current plant sufficient to drive the whole. It is a question whether the advantages the system offers in some very important respects will be sufficient to make it advisable to carry on the train three times the amount of machinery necessary for actually driving the train. The answer to this question depends partly on whether there is any better way, and partly on the size and character of the plant so carried. From the proceedings in the recent arbitration it was clear that in the Ganz system, as installed and tested on the Valtellina line, although half the motors are cut out after half-speed is reached, being used only for accelerating and for braking, the working qualities and efficiency were nevertheless of a high order. Again, at Zossen the step-down transformers are on the motor-cars, instead of in sub-stations.

The addition of weight in this system is serious; but its importance must not be exaggerated, for in passenger-trains weight-efficiency, *i.e.*, the ratio of paying load to dead load, is never high. Thus on the Burgdorf-Thun multiphase trains and on the Chicago continuous-current trains the dead weight is between 1,000 lbs. and 1,100 lbs. per passenger. It is stated that in saloon carriages on ordinary railways several tons of cast iron have been added per coach in order to increase stability. It may truly be objected that each train must carry a little central station of its own; but it may be better that each train should do this, and have it at all times under control, than that there should be along the whole line of railway rotary-converter or motor-generator sub-stations at frequent intervals, with the attendant expenses, and with the necessity of keeping most or all of them running, however light the traffic.

The number of transformations required with this system is not more than with the composite system. As compared with the latter, each train motor-generator is working only when the train is in service, and then under fairly efficient conditions; whereas (at least with an infrequent service) composite sub-stations are working only a small part of their time under economical conditions. Again, the maximum load which has to be met by the motor-generator is that for one train only, and is under the control of the driver; whereas a sub-station may have exceptional loads, resulting from the starting of a number of trains near it at the same time—a condition difficult to deal with.

One very important point in the single-phase alternating-current system is that it involves a much lower "maximum demand" than either the continuous-current or the composite system. As already pointed out, in the latter systems—and the same is true of the three-phase system—the maximum demand occurs at the moment of starting, when the least power is being developed in the train. The output of the generating-station, and the losses in transmission, in transformation, and in wasteful resistance, are then all greatest. Two-thirds of the power produced is lost in resistances. The single-phase system, with its variable-ratio gear, saves all this loss, or a large part of it. The travelling sub-station need not be as large for the same train as a fixed sub-station on the composite system. Whatever transforming-losses may be involved they are much less than in the latter plan, and are not greatest at the moment of least power, but are then relatively small.

If the single-phase system is capable of being applied successfully, there is no advantage in the three-phase system that is worth the extra complication. The good starting-torque of the three-phase motors disappears as an advantage, when compared with the single-phase motor-generator method. There is no substantial advantage with the three-phase system as regards the current to be carried or the amount of copper necessary. For any given power, and with the same voltage between the conductors, the three-phase requires per conductor 0·58 of the single-phase current; but as that current is in three conductors instead of in two, the ratio is 1·74 for the three-phase against 2 for single-phase. This slight reduction in the current to be carried involves at least one extra live wire. If the single-phase system were worked with a second live wire—to make the comparison complete—there would be no need for a rail- or earth-return, and any desired drop might be used. The three-phase system, however, has an undoubted advantage over the single-phase in the smaller first cost of the generators; against which has to be set the greater complication of the switch-gear, etc., required.

Large starting-torque of the single-phase motors is not necessary. Even if they should be so improved as to have a starting-torque equal to that of continuous-current motors, it is likely that a variable-ratio process would still be worth using, especially on lines with frequent stoppages.

Requirements for a General System (*continued*).

The requirements for a general system may now be further examined. Twelve conditions were stated (pp. 68 and 69) which it is essential, or at least desirable, to combine in one system. It was found that the first five of these, which relate to generating the energy and transmitting it to the train, are best complied with by the single-phase system. An examination of the remaining seven conditions leads to a similar conclusion. Taking these in order, they are as follows:—

(6) The overhead distributing-system should be able to serve trains having different kinds of motors and different methods of controlling or working them. The single-phase motor-generator system enables any method of driving to be used on the train. Ordinary 500-volt motors may be arranged as desired, with the advantage, however, that energy need not be wasted in resistances. Or a three-phase generator may be used, supplying three-phase motors on the ordinary or on the "cascade" plan. Interchangeability of traffic between different systems may be secured by suitably varying the kind of motor and of generator which form the connecting link between the distributing-system and the train-equipment.

(7) The condition that a high acceleration must be possible when starting the train is fully met in the single-phase system. The maximum torque that can be exerted by any continuous-current (or other) motors is obtainable under this system with a minimum call on the generating-station and on the transmission-plant.

(8) On a falling gradient, or when stopping, the kinetic energy of the train can be returned to the line as already described, at any speed and very simply.

(9) As regards varying the speed within wide ranges, it is possible to have the full range of speed that is obtained in ordinary continuous-current working, and in addition it is possible to raise the voltage of the dynamo, and consequently the speed of the motors. With separately-excited motors it is possible to vary the excitation, and so to regulate the speed even more easily than can be done with the ordinary series motor. The system does not impose the limits of a synchronous speed, which are imposed with three-phase train-motors. By having a higher periodicity for express lines, a still greater range of speed may be obtained.

(10) A variable-ratio arrangement for starting, for speed-regulation, and for returning energy is provided in a very complete way.

(11) As an ordinary continuous-current supply is given by the motor-generator, any continuous-current system of using motors on the locomotive or distributed throughout the train can be used. Series-parallel coupling of the motors could be used or not, as found best. In any case the controller would be simple, as no resistances would be required.

(12) The trying condition that the train-equipment should admit not only of unlimited extension for different speeds, but also of modification for different distributing-systems, is impossible of fulfilment with any existing plan; but it will be recognized that with the single-phase system the use of motor-generators on the train opens up many possibilities and removes many difficulties which now stand in the way of interchange of traffic between lines with different systems. The motor-generator forms a connecting link between the distributing-system along the line and the electrical equipment of the train; and this link can be varied to suit any conditions. It enables the best method of transmission and distribution to be combined with the best system of train-equipment. Should one main line adopt continuous-current motors on its cars, with a single-phase distribution, the motor-generator as described above could be adopted. Should it be wished to run such a train over another line having a three-phase overhead distribution, it would be possible to use the same equipment, taking energy from one phase only: or a tender might be attached to the train with a motor-generator, consisting of a three-phase motor and a continuous-current generator. This tender would be fitted with proper collecting-trolleys for the two or three overhead conductors. Again, should a railway company decide to adopt three-phase motors on its cars with a three-phase distributing-system, it would be possible to run these cars over a single-phase line by attaching a motor-generator consisting of a single-phase motor driving a three-phase generator. Lastly, in a multiple-unit system designed to run with single-phase distribution and with continuous-current motors on the cars, it might be convenient to attach a tender transforming from the three-phase, or other mode of distribution, to single-phase; so that the motor-generators, if placed on the different cars, would still be in use. This, no doubt, would not be so economical as if the transformation from the three-phase distribution to the continuous current taken by the motors were made in one machine. It shows, however, that

it is possible to interconnect any distributing-system with any system which may be adopted on the trains.[1]

Returning to the single-phase distribution with continuous-current motors on the cars, a multiple-unit system with a motor-generator on each car can obviously be worked out, either with the ordinary series-parallel control, but with the resistances left out, or with automatic or handworked regulation of the generator-fields. A method of control could also be designed whereby car-motors would be worked in parallel from start to full speed; in which case the only regulation necessary would be by alteration of the dynamo fields, and by a switch for reversing the motors. With a motor-generator placed on each car it would probably be found quite unnecessary to control the alternating motors from the front end of the train, as these motors once started and run up to speed would take care of themselves, unless there was a failure of supply. If, however, the control at the front end of the train appeared desirable, it would be a simple matter to arrange.

Combinations of ordinary tramway and railway working may quite possibly come in the near future. With such a system as that now described, the possibility is foreseen that the cars used on the tram lines and light railways which feed the main lines may be run as separate cars at 500 volts, collecting passengers from all directions. They could then be coupled up into a train, and be run at high speed on the main line to town, the necessary motor-generator going with them only on the main line, which would be worked with a high-pressure distribution. On the train arriving at the town, the cars could again be uncoupled and be run through the town as separate cars on the ordinary tramway lines.

The single-phase system lends itself to modifications in a way that compares favourably with either the three-phase system or the continuous-current system. It may for example be applied as a three-wire system on one or two tracks, as with continuous currents. Balancers will not usually be needed, because the transformers for reducing the pressure from the high-tension mains may

[1] The single-phase method described presents little difficulty for goods yards. But if it is desired to get rid of the overhead conductors in such places continuous-current motors could be used, collecting from a track rail fed at low pressure by a motor-generator at the yard. As 500 volts is too high a pressure for live rails under such conditions, a much lower pressure, such as 100 volts, could be used with advantage. At this voltage the motors would be able to develop power enough for the slow speeds required. Such an arrangement is obviously applicable to any ordinary continuous-current working.

themselves be arranged to act as such. If, however, it is desired to balance at points between transformer-stations, static balancers—highly efficient and requiring no attention—can be used instead of less efficient rotary machines. Similar balancers may be used on the trains when necessary. Feeders of different lengths, or carrying different loads, may have their pressure suitably varied by static instead of rotary boosters. Difficulties will not be experienced such as might arise on a three-phase system having unequally loaded branches. Measurement will be simple and more accurate than with the three-phase system, and the control of circuits will be easier.

It is needless to multiply examples of possible modifications. Sufficient has been said to show that the system here advocated possesses great flexibility, and offers at least a practicable solution of the problem of a comprehensive general system of electric traction for railways.

The Authors wish to express their thanks for information kindly supplied by Mr. Blathy and Messrs. Ganz and Company, Mr. C. E. L. Brown and Messrs. Brown, Boveri and Company, Mr. G. C. Cuningham, M. Inst. C.E., General Manager of the Central London Railway, Mr. Eborall and Messrs. Witting Brothers, Mr. E. Huber and the Maschinenfabrik Oerlikon, Mr. Kolben and Messrs. Kolben and Company, and by Mr. P. V. McMahon, Assoc. M. Inst. C.E., chief engineer of the City and South London Railway: also to Mr. A. G. Hansard for his able assistance in connection with the preparation of this Paper.

In Appendix III. are given brief descriptions of some of the systems of electrical traction now in use or proposed, which are illustrated by the diagrams of Plate 3.

The Paper is accompanied by twenty-one drawings, from which Plate 3 and the Figures in the text have been prepared.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

CENTRAL LONDON RAILWAY.

Mr. G. C. Cuningham, M. Inst. C.E., General Manager of the Central London Railway, has kindly given the Authors the following information as to some of the results of the working of that line for the three months September to November 1901.

Train-miles	303,449
Car-miles	1,980,051
Ton-miles	40,442,133
Main-station output,[1] Board of Trade Units	4,113,815
Sub-station output,[1] Board of Trade Units	3,833,207

From these figures are obtained the following:—

	Main Station.	Sub-Station.
Board of Trade Units per train-mile	13·55	12·63
" " " " car- "	2·077	1·936
" " " " ton- "	0·102	0·095

According to these figures a surprisingly high efficiency is attained, viz., 93 per cent. of the main-station output is turned out by the sub-stations.

As will be seen by reference to *Fig. 4*, such a result is possible only if the sub-stations work at full load or more than full load during all the working-time. This result shows a total loss in transmission and transformation of about 7 per cent., which does not include any loss after the energy leaves the sub-station.

APPENDIX II.

CENTRAL LONDON RAILWAY AND CITY AND SOUTH LONDON RAILWAY.

The accounts for the half-year ending 31 December, 1901, show:—

—	Central London Railway.	City and South London Railway.
Number of passengers carried	20,802,650	7,008,842[2]
Gross revenue	£168,359 0*s*. 4*d*.	£62,601 4*s*. 8*d*.
Expenses	£90,544 6*s*. 10*d*.	£29,257 16*s*. 2*d*.
Ratio per cent.	53·78	46·74
Passenger receipts	£162,816 19*s*. 7*d*.	£57,547 12*s*. 2*d*.[2]
Average fare	1·8785*d*.	1·971*d*.[2]

[1] Since the Paper was written the Authors have been informed that the output figures include power used for lifts and for the lighting of trains, stations and tunnels; in fact, all the power used. Therefore the units per train-mile, etc., include all the energy used, outside of the power-house, for the working of the railway.—*July*, 1902.

[2] Season tickets excluded.

If the Central London Railway had received the same average fare as the City and South London Railway, its receipts would have been £8,017 more, and the ratio would have been 51·33 per cent. instead of 53·78 per cent. As the average fare per passenger is nearly equal on the two lines, a comparison has been made on the basis of cost per passenger. To enable this to be done, the season-ticket receipts of the City and South London Railway have been taken at the rate of 1·971*d.*, equivalent to 266,300 passengers, and making the total 7,275,142.

Cost per Passenger.

—	Central London Railway.	City and South London Railway.
	Pence.	Pence.
Maintenance of way, works and stations . .	0·048	0·037
Locomotive and generating power	0·377	0·313
Repairs of carriages, etc.	0·056	0·036
Traffic expenses.	0·401	0·428
General charges.	0·075	0·079
Law charges and compensation	0·013	0·002
Rates and taxes.	0·070	0·064
Government duty	0·005	0.006
	1·045	0·965

The train-miles and passengers per train-mile are as follows:—

	Train-miles.	Passengers per Train-mile.
Central London Railway	614,517	33·87
City and South London Railway . .	495,106	14·7

The mileage of the Central London Railway is 6·43; the City and South London Railway at the beginning of the half-year had 4·75 miles open; but since the 17th November 6·01, or a mean of about 5 miles.

APPENDIX III.

Plate 3 shows diagrammatically the connections of some of the systems that are at present in use, or proposed, and which are referred to in the Paper.

For simplicity the trolley by which the current is collected by the train or car from the distributing conductors is shown as a circle, or trolley-wheel, such as is used on tramways. In practice it might be such a trolley-wheel or a bow or slipper. The conductor by which the current is distributed to the train is indicated as if it were an overhead conductor. In practice the conductors might in some of the systems be placed near the ground-level, either between or beside the running rails. Where the return is by a conductor at or near the potential of the earth throughout its whole length, it is indicated on the diagrams as if the rails themselves were used.

The mechanical connection between the motors and the wheels of the cars is indicated diagrammatically by a belt or chain connection. In practice the connection might be carried out either in this way or by gearing, or the motor might be placed on the axle so as to drive the wheels direct.

Diagram A.—The system shown on this diagram is a continuous-current 500-volt system, in which one conductor is used to distribute power to the train or cars, each of which is fitted with a single trolley or collector. The return is by the rails or by a conductor at earth potential. Where the conductor is placed overhead and a single line of rails with passing-places is used, the conductor has to be doubled at the passing-place so as to allow the trolleys or collectors on the cars to pass each other.

Diagram B.—This shows a continuous-current 500-volt system with two conductors and a return by the rails. The cars are arranged exactly in the same way as in diagram A, each with one trolley or collector. The cars travelling in one direction are supplied from one conductor, and those going in the opposite direction from the other conductor. If the conductor is overhead, and a single line of rails with passing-places is used, this arrangement has the great advantage of avoiding points in the conductor at passing-places, should trolley-wheels be used for collecting the current. The same arrangement of conductors and trolleys can be used with a double set of rails, one conductor being placed over each line. Both conductors are at the same potential, about 500 volts above earth, and can therefore, where necessary, be electrically connected. This system is the one most commonly used for tramways.

Diagram C.—This shows a continuous-current 500-volt system with two overhead conductors. The conductors are connected to opposite poles of the generator, and have, therefore, the full pressure of 500 volts between them. Each car is fitted with two trolleys or collectors, the current passing to the car by one, through the motor, and returning through the second trolley to the second conductor. In this way the whole electrical system can be insulated throughout, and the rails are not used to carry any current, nor are they connected electrically to any point in the system. This system requires insulated crossings in the conductors if only one pair of conductors is used on a single line of rails with passing-places. If trolley-wheels are used, points have to be provided in the conductors, as well as insulated crossings. If slippers or bows are used for collecting the current the points are not required, but the insulated crossings must still be retained to prevent a short circuit at passing-places. With a double line of rails two conductors must be placed over each line, instead of only one as in diagram B.

Diagram D.—This shows a continuous-current 1,000-volt three-wire system with one conductor and a balancing return by the rails. Each car is fitted with a single trolley or collector as in diagrams A and B. The conductor is divided into sections. These sections are connected alternately to one or other side of the three-wire system, and have therefore the full 1,000 volts difference of potential between them. The current passes by the positive feeder to one section of conductor through the trolley, motor and car-wheel to the rails. It then passes along the rails to a car on another section of the conductor, through the wheels and motor and trolley on that car, and so to a section of the conductor which is connected to the negative feeder by which it returns to the generating-station. Should there not be the same number of cars on the two sides of the system the out-of-balance current returns by the rails to the generating-station. With a single line of rails and passing-places the conductor must be doubled as in diagram A.

Diagram E.—This shows a continuous-current 1,000-volt three-wire system with two conductors and a balancing return by the rails. The cars are exactly the same as in diagrams A, B and D, and the system of working is exactly the same as in diagram D, with the exception that as the conductor is doubled throughout no special work is required at passing-places. There is, however, a difference of potential of 1,000 volts between the two conductors. At crossings, and where

lines branch, long insulated or dead sections of conductor have to be used. This system can be used with a double line of rails, and corresponds for the three-wire system to diagram B for the two-wire system. It is perhaps the simplest arrangement possible of the three-wire system, as there is only one collector on each car and no complication at single-line passing-places. All the cars travelling in one direction are on one side of the system, and those travelling in the opposite direction on the other side, which would probably make the difficulty of balancing the two sides of the system much less than in the system shown in diagram D.

Diagram F.—This shows a continuous-current 1,000-volt three-wire system with two conductors and a balancing return by the rails. The cars are fitted with two trolleys, or collectors, as in diagram C. In general the system F corresponds for a three-wire system to diagram C for a two-wire system, but has the middle point of the system earthed. The two conductors have a pressure of 1,000 volts between them, and as each car has two collectors the full pressure has to be used for driving the motors in each car. If ordinary 500-volt motors are used, this would be done by placing two motors in series, as shown on the diagram. As long as the motors are arranged in this way it will be seen that each car has one motor connected on one side of the three-wire system, and the other motor on the opposite side. As the two motors take approximately the same current under all conditions of running, each car forms a balanced load on the three-wire system, and the only current which would pass along the rails from car to car, or back to the generating-station, would be the slight amount due to small differences in the motors or to the out-of-balance current from some car in which one of the motors had failed, and had consequently been cut out of circuit. The arrangement of conductors at passing-places is exactly the same as described in diagram C, but requires better insulation on account of the higher pressure between conductors.

Diagram G.—This shows a composite system such as is in use on the Central London Railway, and which is shown in greater detail in *Fig. 3.* The generator supplies three-phase high-tension current, which is carried by feeders to sub-stations, where it is changed to continuous current at 500 volts. Two sub-stations are shown on the diagram, that marked (*a*) has a step-down transformer and rotary converter, and that marked (*b*) has a three-phase motor driving a continuous-current generator. The system of distribution to the cars and the arrangement of the cars is exactly the same as shown in diagram A. A step-down transformer must be used at sub-station (*a*), as the three-phase pressure supplied to the rotary converter has to be adjusted to give the correct 500-volt continuous-current pressure at the commutator of the rotary converter. At sub-station (*b*) no such step-down transformer is shown, as it is possible to make the three-phase motor work at such pressures as would be used in generating and transmitting three-phase currents.

Diagram H.—This shows a complete three-phase system. The three-phase current is generated and fed at high tension to the sub-stations, where it is transformed down by static transformers to some suitable pressure for distribution to the cars by the three conductors. In this way all running machinery at the sub-station is avoided, but the system necessitates the use of alternating currents on the cars. This is the first diagram in which anything but continuous current is shown as being used on the cars. As three-phase current is supplied from the step-down transformers, three distributing conductors must be carried along the line. Two of these are shown as overhead and the third as connected to the rails. Each car has two trolleys or collectors. Car (*a*) is shown as fitted with a three-phase motor, as in the case of the Burgdorf-Thun

and other lines referred to in the Paper; car (*b*) shows two three-phase motors connected together in cascade. This is meant to represent the Ganz system as proposed for the Metropolitan and District Railways.

Diagram J.—This shows exactly the same system as in diagram H, so far as the generation and transmission to the sub-stations and transformation at the sub-stations is concerned. Three overhead conductors are shown, so that the system is entirely insulated. The car must therefore be fitted with three trolleys or collectors. The car is shown with a single three-phase motor similar to car (*a*) on diagram H.

Diagram K.—This shows a three-phase system in which high pressure is used in the conductors. It represents the system in use on the high-speed experimental line in Berlin, in which the power is transmitted at 10,000 volts and fed to the conductors at this pressure. Each car is fitted with three trolleys or collectors, and the current is taken into the cars at 10,000 volts. Such a car fitted with a step-down transformer and a three-phase motor is shown at (*a*). Both types of car that have been experimented with in Berlin have this step-down transformer, although the arrangement of it and of the motors differs in the two cars. It is possible that in the future a car such as that shown at (*b*) might be used, in which the full transmission- and distributing-pressure is used in the motor so as to avoid the use of a step-down transformer. In such a system the current would be generated, transmitted and distributed from the generator to the motor without any intervening transformation whatever.

Diagram L.—This shows a single-phase system with static step-down transformers at the sub-station. It corresponds for single phase with diagram H for three phase. As the rails, or a conductor at or near the earth potential, is used for the return, one overhead conductor is all that is required. Each car need, therefore, be fitted with only one trolley or collector. Car (*a*) is fitted with a single-phase motor driving a motor-generator such as is indicated in *Fig. 9* and described in the Paper. Car (*b*) is fitted with a single-phase motor, which is coupled to the driving-wheels direct. It is possible that in the future, by the improvement of single-phase motors, such a system could be used for driving the car exactly as the three-phase motors are being used at present, as shown on diagrams H and J.

Diagram M.—This shows a single-phase system, generating, transmitting and distributing at high tension without any transformation at sub-stations. It shows for single-phase current the system corresponding to diagram K for three-phase. Each car would be fitted with a single trolley or collector. Car (*a*) is fitted with a step-down transformer and a motor-generator. It corresponds to car (*a*) in diagram L, with the addition of the step-down transformer. Car (*b*) is driven by a single-phase motor, but the step-down transformer is retained to reduce the pressure to one suitable for the motor. This car corresponds for single phase to the experimental three-phase cars on the high-speed railway shown at (*a*) in diagram K. The car (*c*) shows a single-phase motor taking high-tension current direct from the conductor without any transformation between the single-phase generator and the single-phase motor. It corresponds for single phase to car (*b*) on diagram K for three-phase.

If a single-phase motor can be developed in the future suitable for driving a car direct, the final stage reached would be the simplest system possible and would correspond exactly with the system at present nearly universally used on 500-volt tramway systems; that is to say, the current would be generated and transmitted to the motor without any intervening transformation and by the use of only one overhead conductor. The car would be fitted with a single trolley or collector and the current would pass directly from it to the motor and back by

the rails or an insulated conductor at or near earth potential. It will be seen at once that car (c) in diagram M corresponds exactly with the car in diagram A. The difference is, however, that instead of having to work with continuous current at low pressure in the overhead conductor the current is generated as a single-phase high-tension current, and could therefore be economically and easily transmitted and distributed over long lines. The motor would be worked at high tension instead of at low tension, which is possible with a single-phase motor as the whole circuit through which the high-tension current passes is stationary and completely enclosed and insulated, and there is no commutator or other exposed live connections or parts. The fact that high tension can be used enables such a system to be adopted for the working of long lines and with a car essentially the same as is at present in use on tramways. Such a system depends on the development of the single-phase motor, but if it can be shown that there is a real use for such a motor there is no doubt that it will be developed very rapidly, and probably before long be quite as good a motor as is the present high-tension three-phase motor.

Discussion.

The PRESIDENT moved a vote of thanks to the Authors for their valuable contribution to the Proceedings of the Institution. The President.

LORD KELVIN, G.C.V.O., remarked that he would occupy much time if he were to refer to all he had been led to think of during the reading of the exceedingly interesting Paper, to which every one present had listened with extreme interest and with a great deal of instruction. It was well known how much complexity there seemed to be in electric-traction systems, and yet, how, in some of the arrangements of polyphase, three-phase, two-phase, and single-phase currents, that which at first looked very complicated resolved itself into an exceedingly simple apparatus. The three-phase motor had had full justice done to it by the Authors. In regard to the great variety of appliances necessary to adapt it, on one system or another, to the conditions that had to be observed on railways, the question of the object to be secured was a complicated one. For short railways everything was comparatively simple; but for long railways, whether with few or with many stoppages, for central stations which had also to supply cross lines, it was impossible but that there must be a great complication of means for such a variety of ends. He was glad to see that the Authors boldly attacked the problem of long lines. It was to be looked forward to without any very chimerical optimism as to electrical resources that in the future long lines would be worked electrically as successfully as short lines were worked already. There were many ways of carrying out the electrical method for long lines, and, as the Authors had justly said, they essentially involved high-tension currents. He had admired the courageous argument and the strong case which the Authors had put forward in favour of the simplest of all alternating-current systems, namely, the single-phase system; and it was almost dramatic to find how, after being led, in Appendix III. of the Paper and the diagrams illustrating it, through a splendid maze of apparatus, the members were brought back to the point from which they started. To railways the simplicity with an alternating-current system, if practically achieved, would certainly be a great triumph. He would only ask for a little consideration for the continuous-current system. It had Lord Kelvin.

Lord Kelvin. been said that there was but one possibility, viz., constant voltage, whether alternating or continuous current was used. That idea had been learned long ago; but while it was being learned there had been many who had thought of the other system, the constant-current system. Probably almost every practical electrician would say that was quite impracticable and out of the question in regard to electric traction on railways. Still, he thought it was worthy of more consideration than it had obtained; and he suggested that after all the extreme simplicity of constant continuous current in one insulated line for the high-pressure circuit might possibly be found good for traction on long lines. That method had been advocated long ago by Messrs. Siemens, and they had shown how it could be practised. It had been much better known and more in favour in some applications 15 years ago than it was now; but he would suggest that the many acute, intelligent, and active minds concerned with the subject might be turned back upon some of those old questions. It must not be imagined, however, that he was putting it forward as a ripe practical proposal. He was only suggesting it as a subject for reflection, with the possible outcome of falling back on the continuous-current system throughout, instead of merely in the locomotive motors. He had listened with much interest to the suggestion of a locomotive sub-station. On any system, even the simplest, there were central stations and sub-stations, and there was a considerable degree of complexity. It was an interesting idea for alternating-current distribution, that the sub-station might be as economically carried on a locomotive as placed in a fixed position. According to the Authors, the only real objection to it was the weight carried on the locomotive, and even that objection was practically disposed of by the statement that in some instances several tons of useless material had been added, for the purpose of giving stability. Whether the space occupied, the number of parts and conductors, and the electrical complication on a locomotive would form serious objections to the Authors' proposal he did not know; but they did not seem to him likely to be so, because things became greatly simplified when they were perfectly methodized. The idea of an electric locomotive carrying the sub-station, although perhaps it now looked no more practicable than the steam-engine on wheels had looked to James Watt and his contemporaries, might yet be realized and found good; and he would watch its development with great interest. One thing in the Paper which might surprise many was the voltage lost in the transmission of the return current by iron rails. He had been somewhat startled to hear how much loss there

was owing to the fact of the currents not passing equally through the whole material of the rail, but being in some degree "skin" currents. A great deal was known about that effect in relation to copper conductors, and something in regard to iron conductors. A highly complicated physical and mathematical problem was introduced by the magnetization of the iron itself, and the variation of that magnetization which was essential to the carrying of an alternating current by an iron conductor. In conclusion, he considered the Paper was of great practical importance, and he was sure he was expressing the feelings of the members in thanking the Authors for their valuable communication. Lord Kelvin.

Colonel R. E. B. CROMPTON, C.B., remarked that the Paper presented for discussion a matter which every one believed to be the great engineering development of the future, namely, the substitution of electricity for steam on railways. He would not say in such an Institution that steam was doomed; but electrical engineers had really to discuss the question from the point of view that, to some extent at least, the age of electricity had been reached. The problem put before the Institution by the Authors was to determine the best lines on which large electric-railway undertakings were to be carried out in the future. The members were indebted to the Authors for putting together in a convenient form the various ways in which, according to present knowledge, a large electric railway could be worked; and, as far as the Authors dealt with facts, every one must thoroughly agree with them; but when they came to choose between the various systems it was necessary to criticize their selection. He was one of the few persons who had had to make a responsible design for and to consider the whole problem of working a railway 180 miles in length by means of electric power. He alluded to a Trans-Himalayan Railway on which he had had to report to the Government of India about two years ago. At that time he would have been greatly advantaged had he had before him the Paper under discussion, as it assembled in a handy form many data which it had taken him several months to collect for the purpose of his report. He had had before him then only the possibility of carrying out the railway on the composite system illustrated by diagram G (Plate 3); that was to say, a line 180 miles long was to be provided with power from either one or three centres, two- or three-phase alternating current at high voltage being supplied to converting-stations placed at intervals along the line, and there converted, first by transformers and afterwards by rotary converters, into continuous current at about 750 volts, which at Colonel Crompton.

Colonel Crompton. the time had been considered to be the highest pressure allowable for a trolley-wire on the railway. He had gone through a considerable number of calculations in order to ascertain what was the best distance apart of those converting-stations, all things being taken into account. The Authors must face great difficulties when they recommended any one system as the best for all conditions; for everything depended on the conditions. The railway he referred to was to be carried through the Himalayas, and the difficulty of constructing it would be enormous. It would have to be carried along the face of stupendous cliffs, and to be protected by snow-sheds for large portions of its length, and every inch of extra width would add greatly to the cost. In fact, the difference between a 2-foot 6-inch and the metre gauge would amount to something like £250,000. Under those circumstances it was evidently quite impossible to carry out the work except as a single line with a large number of crossings, and it was only when the introduction of crossings into an electric railway system was considered that it began to be apparent how much the matter was complicated by the converting-stations and by the conditions of the train-service, involving some trains standing in the crossing-places while others were travelling in the spaces between them. In preparing his report, the spacing of the converting-stations, so as to get the best results between the crossings, had been a question of extreme difficulty. A large amount of time and thought had had to be given to it, which had resulted in the converting-stations being placed about 7 miles apart: and even at that long distance he had been much dissatisfied with the results obtained. The cost of the staff included not only the wages of the men in the converting-stations, but also the expense of the extra inspecting-staff necessitated by the risks of interruption of the service due to any breakdown in the converting-stations; and these items added considerably to the cost of working the line. With the greatest relief, therefore, he had found, just as he had completed his design on system G, that Messrs. Brown, Boveri and Co. had been highly successful on the Stansstad-Engelberg line with system H, namely, the use of three-phase current, step-down transformers, two trolleys, two conductors, and rail-return. Considering the extraordinary flexibility of the system—how on one part of the line cars carrying their own motors could be run in the ordinary way, and on the 1-in-4 gradient a locomotive could be attached suitable to the particular incline; and what safe results could be obtained under those circumstances in descending the incline of 1 in 4, by the device of returning electrical energy to the line—he had felt that the problem had been

solved in such a simple and satisfactory way as to carry conviction; and he had believed at the time that the system constituted a new departure which would be largely put into practice and imitated before any important advance on it was made. Since then two years had elapsed; he had visited the line again; and he did not think any advance had yet been made on this system. As the Authors pointed out, with a change-speed-torque system wonders could be done—a fact which was well known. A change-speed-torque was the electrician's "philosopher's stone," that had so often been sought. It had been pursued by Heilmann in the design of his locomotive, the complexity of which had caused the abandonment of the idea. His own opinion of the importance of the matter was shown by the fact that he had devoted to it two or three pages of a presidential address,[1] delivered a few years ago. If the Ward Leonard system, which was theoretically perfect, could be brought into the domain of practical mechanical engineering, then no doubt it would be possible to use single-phase alternating current, with its extreme simplicity, and all the beautiful devices shown in diagram L, and possibly also diagram M: but the "if" was a very big one indeed; and although he did not at all despair of seeing the system carried out in practice, it had not been done yet. When it was remembered that the inventor had been working at it for 11 years and had not made very much progress, it seemed that there must be something in the system which would militate against its general use. The beauty of the idea of carrying the converters on the locomotive had been remarked upon by Lord Kelvin; but Colonel Crompton believed that if the electric locomotive was to beat the existing locomotive for long lines, which was a difficult thing to do, it would not be by introducing complexity into its machinery. It was well known that the cost of maintenance of locomotive machinery was much higher than that of fixed machinery, which could be looked after in the power-house, and the expense of which could be kept down to a small sum. A locomotive, whether steam or electric, worked in ordinary weather by ordinary drivers, with all the eventualities and accidents which might occur on the road, was in quite a different position from housed machinery. It followed that, if electrical engineers were to beat steam machinery, it must be by greater simplicity on the road, and by bringing the complexity inside the power-house; and he did not think for one moment

Colonel Crompton.

[1] Journal of the Institution of Electrical Engineers, vol. xxiv. p. 4.

Colonel Crompton that such a caravan of electrical apparatus as was shown in *Fig. 9* was likely to yield the solution of the problem. The merit of system H was that it was much less complicated, even in regard to the locomotive itself, than system G; in fact, it was less complicated than any of the systems A—G. Any one who had seen the Burgdorf-Thun or the Stansstad-Engelberg locomotives would agree that they were easier to build, and had far fewer parts liable to get out of order, than the ordinary continuous-current locomotive with all its resistances and series-parallel starting-devices, etc. They were exceedingly simple locomotives, and the credit of them was due to the skill of Mr. C. E. L. Brown. If anything was to be gathered from what had been actually carried to a practical conclusion before, it was necessary at present to stop at system H. Experiments might be made with the more advanced systems shown in the diagrams, and eventually the variable speed-torque ratio might be reached; but it was a curious thing that once change-speed-torque could be introduced in locomotive machinery many other systems of working became practicable which were not confined to electrical machinery. For instance, the Diesel engine could be used for running the trains and would be a means of obtaining great economy. It appeared extraordinary that, as the efficiency rose in going from ordinary simple engines to compound, from compound to triple-expansion engines, from triple-expansion engines to internal-combustion engines, and finally to the Diesel engine, the engineer was more and more bound to constant, or approximately constant, speeds. Then, if a change-speed-torque arrangement was introduced, there was obtained at once the most efficient means of changing the energy of fuel or water-power into the energy required on the line which it was possible to have. But, as he had said, it was a big "if," and the problem had not yet been successfully worked out. He thought the Authors had shown how necessary it was to direct attention to the problem of devising a thoroughly simple variable speed-torque arrangement.

Mr. Siemens. Mr. ALEXANDER SIEMENS considered that the gist of the Paper was contained in the twelve requirements for a general system; and although he differed from the Authors in the way they had expressed one or two minor points, on the whole he thought they had correctly set forth the objects to be sought. But when the Authors came to their solution of the problem, he believed there was ample scope for differing from them. On the first point, as to the generators in the power-station, he entirely joined issue with them; and he would recall Lord Kelvin's remark that the constant-current system was really being badly treated, for, while its

applications had not been very numerous, it had many advantages. Mr. Siemens. With constant-current motors on a train, any number could be put in series; they could be put straight into the main circuit and could be regulated with the greatest possible ease, because regulating constant-current motors meant short-circuiting parts of them, which could easily be done. In fact, there was no large difference of potential the moment they were short-circuited. In that way they presented great advantages from the point of view of regulation; and as they did away with all transformers, either rotary or stationary, their application ought to be studied more. He would not go into details, but would remind the members that Mr. H. Cuénod had written a little pamphlet, issued at the Paris Exhibition, 1900, which put together their advantages. The Authors quite overlooked the claims of the constant-current system. They observed that the drawback to the system put forward in the Paper was that there was so much machinery to be carried; and Colonel Crompton had made the same comment. Therefore it might be interesting to have figures about the weights; and Mr. Wilson, one of his assistants, had kindly put some together, simply taking standard sizes: these figures had reference to the arrangements shown in *Fig. 9.* Taking first a train running at 60 miles per hour, an eight-coach train would weigh, with passengers and traction-equipment, 189 tons, and the car with the motor-generator would weigh at least 49 tons, that was, an addition of 26 per cent. to the weight which had to be hauled. The motor-generators would consist of two units, each being able to produce 260 kilowatts at 430 revolutions. As the Authors mentioned, electric traction had really its best opportunity where the trains ran very frequently—where, in fact, there was something like a tramway service. But if such a train consisted of three coaches and had to run at 60 miles per hour for long distances, the weight of three coaches, equipped, would be about 71 tons, the motor-generators in the car weighing 34 tons, or 49 per cent. of the total weight. The motor-generators would be of the same size, and each should be able to produce 160 kilowatts at 450 revolutions. To employ the system for suburban trains—running at about 20 miles per hour and stopping every ½ mile for, say, 20 seconds—much larger motor-generators must be used; for although the average power which such a generator would have to exert would be only 160 kilowatts, for quick starting 540 kilowatts would be required; and as it would not be right to overload a motor-generator more than 50 per cent., it would be necessary to put in 360-kilowatt motor-generators, which meant

Mr. Siemens. two machines each capable of generating 360 kilowatts. Then the weight for three coaches, with the equipment a little stronger for the rapid starting, came out at 72 tons; the motor-generator and its car would weigh 55 tons, which was 76¼ per cent. of the total weight. The effect of that would be evident in the coal-consumption; and it was a pity the Authors had not stated in the Paper the coal-consumption per train-mile on the various electrical railways, and whether the consumption was so low that an increase of 76 per cent. did not matter. He did not overlook the fact that one very important point in favour of the system was that the maximum demand was levelled down, and that the generating-station could therefore be somewhat smaller. The Authors admitted the objection that each train must carry a small central station of its own, but they did not go far enough: as Lord Kelvin had observed, it was only a sub-station. Why did they not put a central station on the train, and do away with all generating-stations, all conductors, and all troubles in collecting? Then they would have a Heilmann locomotive, about which there was the same thing to be said as Colonel Crompton had said about the Ward Leonard system—Why had it not been introduced more extensively?

Mr. Dawson. Mr. PHILIP DAWSON considered the Paper was exceedingly interesting at the moment, because the application of electricity to traction on the metropolitan and suburban lines of such towns as London, Manchester, Glasgow, and Liverpool, would, he believed, be a feature of the twentieth century. Electrical traction was particularly fitted for such lines, and its main advantage lay in the fact that by electrical means rapid acceleration could be obtained, which was not possible with the steam-locomotive. There were two points on which he would like further information. In the figures relating to the Central London Railway (Appendix I.), the Authors gave the ton-mileage of the trains, and he would like to know whether those ton-miles referred to empty trains, or whether allowance had been made for the passengers carried, and if so, what allowance had been made; because the weight of the passengers carried might mean something between 25 per cent. and 30 per cent. of the weight of the train. He presumed that by "output" the Authors meant the output at the central station at Shepherd's Bush: also that the figures in the Appendix showing the Board-of-Trade units per ton-mile had been obtained by dividing the number of units delivered at Shepherd's Bush by the ton-mileage. He noticed 102 watt-hours generated at the main station per mile

Mr. Dawson.

run, or 95 watt-hours delivered from the sub-station. He did not quite understand those figures, because in the evidence given at the recent arbitration it had been stated that on the Central London Railway 41½ watt-hours were consumed per ton-mile, which was rather less than half what the Authors gave. It might be accounted for by the fact that the lifts and the lighting of the tunnels, stations, etc., were included in the total output of the main station. He was informed that the power taken by the train was about 50 per cent. of the total output, and the remaining 50 per cent. was absorbed in working the lifts, in lighting the stations, and in transmission-losses; and that would reduce the Authors' figure to that which had been given in evidence before the arbitration.[1] With regard to the adoption of a three-phase system for traction in America, he held no brief for that country, but he had heard from the heads of the General Electric Company that they had been experimenting for many years on the adaptability of the three-phase system to traction, and the question of cost had been the one which had hindered them from putting it forward generally. He could not agree with the Authors that there was no satisfactory system actually at work for longer suburban lines, because there were lines extending some 20 miles or 30 miles from the central station, with heavy trains, weighing anything between 40 tons and 180 tons, which were being worked at fair average speeds, considering the short distances between the stations. Moreover, they were being worked successfully from a financial point of view—which after all was the chief point. Until capital could be obtained to back engineering enterprises, there was not much for engineers to do. With regard to longer lines, it seemed to him that the question of working main lines lay in the dim future. It was quite possible to work main lines electrically, but he did not think it would be possible to work them more economically by electricity than with the existing good locomotives. Trains made the journey between London and Glasgow in considerably less than a day, and supposing that service were accelerated by 1 hour, it would be effected at a heavy capital cost, as well as a largely increased working-cost; and he doubted strongly whether the resulting increase in traffic would justify such expenditure. In Appendix II. to the Paper the items relating to maintenance of way, works, and stations, locomotive and generating power, repairs of carriages, etc., were higher on the Central London Railway than on the

[1] See footnote 1, p. 81.—Sec. Inst. C.E.

Mr. Dawson. City and South London Railway. It should be borne in mind that this might be accounted for by the permanent way of the Central London Railway not being as good as that of the City and South London Railway. The extra costs could not be due to the system itself, because the maintenance of the permanent way, the working-expenses of locomotives, and the repairs of carriages, were practically the same in the one system as in the other. Law-charges, again, were higher for the Central London Railway than for the City and South London Railway; but that did not appear to have anything to do with the difference in system. If the charges were equalized, it would be found that the Central London was actually cheaper, per passenger, than the City and South London line. It was difficult to draw any conclusions from the Table of comparative cost of transformer-stations for the alternating-current system and for the composite system, because the Authors stated that the prices there given included "a fair proportion" of spare plant: he would be glad if they would state what that proportion was. Rough calculation seemed to show that the prices, as far as transformers and rotary converters were concerned, were much too high in the composite system. He could not quite agree with the Authors' statement that there was practically no electrolytic action with alternating currents. He would like to know whether that statement was based on the results of experiment; if so, it would be interesting to have some of the results obtained. His experience, with the fairly low frequencies which must be adopted for traction with alternating currents, was that the electrolytic action was nearly as bad as with continuous currents: the difference was that with continuous currents the resulting damage was limited to an area which could be predetermined, and safeguarded by means of additional return cables or negative boosters; whereas with alternating currents the area was not limited, and the damage was likely to be caused over the whole system. He agreed with Mr. Siemens that the kernel of the Paper was contained in the requirements for a general system, and in the methods which the Authors proposed for meeting those requirements. It seemed to him, from the experience he had had during the past 12 years in connection with electrical traction, that, practically, the system, although a very attractive one, would not be generally adopted, at all events for a large number of years. It seemed rather an expensive method of getting a simplified system when, with a train requiring, say, 1,500 HP. to drive it, double the power was needed to work the motors. The system not only

added to the dead weight, but would involve heavy additional capital expenditure, and the maintenance of such a perambulating system would be exceedingly heavy in cost, and more difficult than that of stations equipped with rotary converters. Mr. Dawson.

Mr. H. A. Mavor remarked, with reference to *Fig. 9*, that it seemed strange that the Authors should not have more fully considered the possibility of interposing a mechanical device. For example, the application of a motor for driving an ordinary locomotive by compressed air would be a much simpler, lighter, and cheaper method of doing the work than was suggested in the diagram. He quite agreed with Mr. Dawson that it was looking far into the future to think of working long-distance traffic by electricity, and that, if it was to be done at all, it must be done at a lower cost. When it was considered that the existing steam-locomotive was a fairly efficient user of heat, it was difficult to see where any gain was to be realized by the adoption of electrical traction if it was necessary to begin by generating steam in a steam-engine to drive a dynamo producing electric current, to transform this current for the line, to re-transform it again on the machine, and to transform it again for application to the wheels. The engineer who had that problem to face, and proposed to solve it by transmission of power, had certainly a most difficult task before him. He thought, however, that the Authors had dismissed too easily the possibilities of the use of gearing. There was a new gearing which had been applied in Glasgow to motor-cars, a gearing in which an intermediate wheel was used, rotating round the driving-wheel, between it and the driven wheel. By allowing the intermediate wheel to rotate round the driver, it was possible to vary the rate of transmission to any desired extent, and that had already been done on a small scale. It did not solve the problem of change-speed-torque; and it appeared likely that if a solution was to be found, it was more likely to be found in the use of a compressible fluid between the motor and the wheel than in the use of gearing. Mr. Mavor.

Major P. Cardew remarked that the Paper dealt with a question which was certainly one that called for debate; and it was pleasant to be able to discuss it in an atmosphere free from the obscuration arising from special pleading. The Authors alluded to a recent arbitration, in which he had had the pleasure of taking part on the losing side. The result of that arbitration had not been a surprise to him, nor did he suppose it had been so to many. The reference to the arbitrator, under the Major Cardew.

Major Cardew. existing conditions, had practically decided the question; but he thought it was generally conceded that the defeated side had retired with the honours of war. He was largely in accord with the Authors in their arguments, although he had to differ entirely from their conclusions. As to the Valtellina line, his information was that the goods trains had been running for some time, and that the passenger trains were expected to run shortly. He could not say definitely why the passenger trains were not yet running, but he believed there had been difficulties unconnected with the electric system. With regard to junctions, the Authors stated that multi-phase systems were at a disadvantage in requiring the use of at least two live conductors, instead of one. He thought it was hardly recognised that in the ordinary third-rail system there were two charged conductors close to each other, and there was really more difficulty in getting over junctions with charged rails practically on the same level as the running-rails, than there was with overhead wires. The result of putting conductors overhead was to simplify the junction, and not to complicate it. It might be remembered that at the arbitration a triangular junction had been put forward which was to upset the Ganz system and throw it out of court; but a little examination of the conditions had removed the difficulty. Where there were charged rails on a level with the running-rails, and particularly where there was a double insulated system and two charged rails, junctions presented great difficulties; a long length had to be left out, and, unless fairly long trains were used, it was difficult to bridge the gap. The question of shunting-yards required to be considered by itself. In the shunting-yard, engines were required to work trains at a low speed, and it was very uneconomical to equip such a yard with the same rolling stock as was used on an express line; the proper plan was to have special locomotives to do the work. That solution of the problem was now being largely adopted on the Continent, where accumulator locomotives were used for such special work, with highly satisfactory results. He quite agreed with the Authors in regard to return conductors. He had always considered Messrs. Ganz and Co. to be right on most points, but he could not agree with their insistence on using the running-rails, or any iron conductors, with alternating currents, the increase of resistance with such currents being very considerable. In some Cantor lectures[1] on "Electric Railways" which he had delivered during the past year he had gone into that matter to some extent,

[1] Journal of the Society of Arts, vol. xlix. p. 641.

and he had come to the same conclusion as the Authors, namely, that the proper solution was to have a partially insulated conductor connected with the earth at the point of generation, and the bulk of that conductor should be copper, or some non-magnetic metal. As to the negative-booster question, the Authors attributed the idea to Mr. Kapp, but he thought it was one of his own invention, having been published by him in May, 1894.[1] It had been sent to the South Staffordshire Tramways Company, who at the time had certainly been in need of negative boosters, but whose financial position had not allowed of their trying them; and they had put the thing aside for some years in a drawer. Mr. Kapp had taken out a patent on the subject, but Major Cardew had always understood that patent to be invalidated by the publication referred to. He thought the Authors hardly attached enough importance to the desirability of a low frequency from the point of view of the induction motor. An induction motor became a far more efficient and practical machine at a low frequency than it was at a high frequency, but there was the difficulty of lighting to be got over. With regard to the Authors' conclusions, he agreed with the previous speakers, and he thought there was a general unanimity of opinion as to the Ward Leonard system, which he had dealt with also in his Cantor lectures. It was certainly a fascinating system, on account of the reduction of loss during the period of acceleration; but when it was worked out, the extra weight and cost involved, and the extra complication and risk of breakdown in all the machinery, hardly allowed it to come within the range of practical politics. Major Cardew.

Mr. W. H. Massey remarked that he was sorry his friend Colonel Crompton had not consulted him about the Himalayan Railway, because he had settled the question in principle finally, as he thought, about 18 years ago in conjunction with the late Professor Fleeming Jenkin, whose worthy son one of the Authors was. He would like to know whether the Authors had considered what, for the sake of brevity, he would call the Massey system. It had seemed to him then—as it seemed to him now—that if electricity was to be introduced on railways the simpler the appliances could be made the better; and he had suggested the use of two double-commutator motors on each coach, and an electromotive force of 2,400 volts on every section of railway. Now that 500 volts had been made the standard, he saw no harm in reducing it to a working-pressure of 2,000 volts; but he still adhered to the Mr. Massey.

[1] Journal of the Institution of Electrical Engineers, vol. xxvii. p. 463.

Mr. Massey. double-commutator motor, one on each axle of a coach. Speaking as a mechanical engineer, having only a practical aquaintance with electricity, he could not see where the difficulty arose, except on very long lines, and there, with due respect to the Authors and others, he did not see how electricity obtained by using fuel was to oust the locomotive. He used the word "section" advisedly, because with a general system of distribution from one or two large stations, if the stations broke down, or anything happened to the supply conductor, the whole system was disorganized; whereas by using sections, in the event of one section failing, it could be coupled up temporarily to its neighbour, and there need be no serious interruption in the ordinary traffic of the line. With regard to alternating currents and electrolysis, experiments he had conducted about 4 years ago had left no doubt whatever that, provided the frequency was low enough and the current sufficiently large, electrolytic action occurred just as badly, or was even worse, with alternating currents than with continuous currents. With a view to simplification he would propose, instead of an overhead wire, an "over-side" conductor on 15-foot poles between the two lines. As a return, no doubt a copper conductor ought to be used at or about the earth's potential, and not the rails. The objection to using rails as a return, from the point of view of the man who had to repair the permanent way, seemed fatal to the practice. Polyphase currents and cascades were exceedingly fascinating subjects, although he had not been fascinated to the same extent as Major Cardew. It was possible to introduce fascinating devices in continuous-current systems. He would make the suggestion that the magnets of a continuous-current machine should be designed so that, when required, they could rotate in the opposite direction to that of the armature; and he threw out that suggestion as a means of getting rid, at any rate partially, of resistances for regulation. There was one point which he had searched the Paper through to find, and that was the question of cost. It was always an intellectual treat to consider electrical possibilities, but, as engineers, they had to take into account that great "force of Nature," £ *s*. *d*. He did not see how it was possible for any electric system depending on fuel to compete with the steam-locomotive on long lines.

Mr. Molesworth. Mr. W. H. Molesworth remarked, with regard to the statement in the Paper as to the fall of pressure in uninsulated rail-returns of a 500-volt tramway system, that the proposal to allow a larger fall of pressure was one that would hardly be accepted with pleasure by any one having interests in gas- or water-mains. It had

been pointed out at the Glasgow Engineering Congress that if the drop exceeded 1 volt injury to gas- and water-mains did result. Experience in America showed that considerable damage had already been done to bridge-structures and in mains by electrolysis, where the drop of voltage was excessive; and the drop mentioned in the Paper would be so. The electrolytic action of alternating currents of low frequency, as advocated for railways, was as serious as that due to continuous currents. Mr. Molesworth.

Professor ARNOLD LUPTON remarked that he would venture to join Lord Kelvin, who had made an appeal on behalf of continuous current. He did not direct his attention to the motor on the locomotive, but to the generating-station. It had been his business during the past year to consider possible methods of working large central power-stations, and the working of a long railway by electricity was similar in some respects to the work of such a power-station. Looking at the matter practically, the existing electric railways were small lines, but ten, twenty, thirty or fifty years hence they would be much bigger; and during that period the working must be continuous. No engineer desired to discard the whole of the plant every five years, and therefore machinery was required that would work with newer developments. He had had to consider how he could start a generating-station to which he could keep adding month after month and year after year: and there seemed to him to be great advantages in continuous current. With half-a-dozen separate generating-stations connected to the same mains and each containing a large number of machines, every one of which had to be synchronized, and driven perhaps by a variety of engines, such as reciprocating steam-engines, steam-turbines and gas-engines, it seemed to him that serious practical difficulties arose with alternating currents. He understood that with continuous-current machinery any kind of engine could drive the dynamo, and all that was necessary was to raise the current to the necessary voltage and send it into the main. One main might be joined to another main, and a station 50 miles off be connected with a station nearer at hand; so long as the voltage was maintained all would go well. There were said to be many practical difficulties about continuous-current motors and dynamos; but makers had expressed their willingness to make a 4,000-volt dynamo to order, and to guarantee its efficiency; and if they could do that, they might soon make an 8,000-volt dynamo. He was not prepared to say that the excellent existing locomotives would be superseded by electricity; but if they were, it would be by means of some engine which generated Prof. Lupton.

Prof. Lupton the current with the maximum of economy. It was said that the gas-engine had the maximum economy; that 1 lb. of cheap fuel per horse-power-hour was sufficient. There were stated to be certain kinds of gas-generators which yielded the whole cost of the fuel in residuals. If that was so—and it was put forward by some of the most eminent men in the land—that would be the line on which the thing might be started. While he agreed as to the excellence of the locomotive and the difficulty of superseding it, every day new electric lines were being built and worked, and Colonel Crompton had stated that he had considered the question of working an electric line 180 miles in length. It had been said that this would not happen, but it was already happening.

Major-General Webber. Major-General C. E. WEBBER, C.B., remarked that he had known one of the Authors for 16 years, and had watched his career and his devotion to alternating currents, which had never varied during the whole of that time. He thought it was a pity more had not been heard in the discussion from those who knew a great deal more about steam-locomotives than did electrical engineers. The arrangement shown in *Fig. 9* was admitted to be a complicated system—one which had practically never been put to work. It would be seen that there were five transformations of energy between the terminals of the generator in the stationary generating-station and the driving-axle of the locomotive. The Authors might have given a practical example not only of the losses, but also of the cost in a line, say, 50 miles long, the average efficiency of which might be considered as if it were fed at a point midway between the two ends. In working out the efficiency resulting from those five transformations of energy it might fairly be said that the loss of efficiency between the generating-station and the driving-axle of the locomotive would be something like 50 per cent., or in other words, that generating electricity at 2½ lbs. of coal per kilowatt in the station would mean expending 5 lbs. of coal on the locomotive. It would be interesting to have from locomotive engineers some indication as to how they regarded that question. It would be remembered, no doubt, in dealing with it, that the generation, transformation, and application of the power took place within the steam-locomotive itself; whereas, in the locomotive described in the Paper, only a portion of that work was done, and to the cost of it must be added a percentage of other costs, not only of the generating-station 25 miles away, but of the overhead conveying line, which could not cost less than £750 per mile. In addition, there was a share of the cost of the transforming-stations along the line, and other costs which did not enter into

Major-General Webber.

the question with the steam-locomotive. The costs given in one instance showed that the Authors wished to impress the members with the heavy expense of transformation of continuous as compared with alternating currents. He understood that the figures in the Table at p. 53 had been furnished by contractors, who, no doubt, were prepared to carry out the work at those rates; but there was one item, "switch-gear, starting-gear, and connections," in which the cost for continuous current was nearly three times as much as that for alternating current, namely, in the ratio 3·3 : 1·3. He thought some explanation was required from the Authors as to what they included in that item. How the starting-gear came into the figure he did not know; and how the connections would produce such a result as that required explanation. With regard to the buildings to contain static transformers and rotary transformers, the comparative costs of £0·6 and £1·8 per kilowatt might be correct for towns, but he very much doubted whether the costs of buildings for static transformers and for rotary transformers alongside a line would be in the ratio 1 : 3. He thought the Authors put the case against continuous current in a slightly exaggerated form. With regard to shunting, there were difficulties which he did not think they had contemplated. At Shepherd's Bush station, on the Central London Railway, although there were trolley-wires for doing the small amount of shunting required, their use had been abandoned, and steam-locomotives were now doing the work, which, it would be thought, under the circumstances, the railway would have made an effort, and even a sacrifice, to do by means of electric locomotives.[1]

Mr. Raworth.

Mr. J. S. Raworth remarked that it was doubtless the reference in the Paper to main-line traffic that had brought so large an audience together in the Institution. In the application of electricity to metropolitan and suburban lines no serious complications were required, and certainly not one-half of the devices shown in the diagrams: it was the problem of the application of electrical working to main-line traffic which had led the Authors to put before the members the somewhat complicated arrangement whereby they proposed to get over some of the difficulties. But from their twelve requirements which had to be met in designing a system of electric traction for main-line railways they appeared to have left out the most important of all, namely, a system whereby the current could be conveyed from the road to the train. He did not know of any system yet devised, for any rail-

[1] See Mr. d'Alton's remarks at p. 177.—Sec. Inst. C.E.

Mr. Raworth. way whatever, that was fit to be put upon a main line such as the London and North Western Railway or the Midland Railway. None of the railway engineers present would be satisfied to put down bare conductors, at 500 volts or more, at the level of the rail, as was done in underground railways with perfect success; and he did not see how it was possible on English railways to put up a high-tension trolley-wire that would meet the conditions. In the Paper an interesting experiment was described which had been tried in Berlin, to show how high-speed railways could be worked with overhead wires. There were three wires, which took up a large amount of room; but the engineers in Germany were in the happy position that they could go 240,000 miles into space before they came to any obstruction; whereas in England it was not possible to put so much as a bandbox on the top of a train. It was quite possible to work tramways, where the head-room was usually 18 to 20 feet, with a trolley-wire; but how the railway engineer was to fix up a trolley-wire in a satisfactory and perfectly safe manner, and yet be able to collect a current from it in a practical way, he could not see. In every one of the Authors' diagrams a trolley was shown, but at a speed of 70 miles per hour no locomotive engineer would know how to keep that trolley on the wire, especially on a curve. If it were supplanted by what was commonly known as the Siemens "sky-scraper," other difficulties arose. Before much time was spent in considering what electrical method should be applied for using the power on the locomotive, it was well to consider how to convey the current from the railway to the locomotive itself.

Mr. Hammond. Mr. R. Hammond observed that, like many other electrical engineers, he had been fully expecting to hear from railway engineers what were the difficulties which struck them in regard to the problem. Possibly they were reserving themselves, and after they had heard all that the electrical engineers could say would destroy them utterly. There seemed to be unanimity of opinion on the part of electrical engineers that long lines of railways must be fed by high-tension alternating currents. It had been suggested that possibly it would be better to have continuous currents: these involved commutators, and at a certain pressure commutator troubles became practically insurmountable. It was a remarkable fact that the very voltage Mr. Massey had suggested 18 years ago was practically the limit of the present time; whereas with alternating currents at that time the limit had been about 1,000

Mr. Hammond.

volts, and now the pressure on the Valtellina line was 20,000 volts. It was only by the use of alternating currents that high pressure could be obtained, and it was necessary to use high pressure because, as was well known, the higher the pressure the smaller the current to be carried, and the actual loss of energy on the line was the square of the current multiplied by the resistance. On a visit to America during the past year he had been specially interested in finding that there was a growing opinion that main-line railways would look to electric railways as their feeders. He had visited that series of most interesting lines around Cleveland—lines varying in length between 30 miles and 60 miles. In every case in America the composite system, as it was called by the Authors, was in use; that was to say, when any considerable distance had to be traversed there was high-tension transmission, and conversion at sub-stations to the pressure required by the continuous-current motors on the car. It had therefore been with some interest that on his return from America he had gone to the north of Italy to see the Valtellina line, on what was commonly known as the Ganz system. He had found it working so far as goods traffic was concerned, but not for passenger traffic. On the Valtellina railway the first transmission-line conveyed alternating current at 20,000 volts from Sondrio to nine sub-stations along the 67 miles of line, where the pressure was reduced to 3,000 volts, at which pressure the current was conveyed along the trolley-wire and used on the train. There the principle pleaded for by Colonel Crompton, with whose remarks he entirely concurred, was fully carried out. The less the work the current was compelled to do between the point of generation and the actual point of utilization, the sounder the system seemed to be. It was so in lighting. He had had in hand during the past year a large scheme in connection with the electric lighting of the City of Dublin, involving an expenditure of £250,000, where he had battled for that principle. There high-tension three-phase currents were generated and so delivered at some distance to the consumers. On the Valtellina line the goods traffic was worked with locomotives weighing about 46 tons, of which 23 tons was the weight of the electrical equipment. The electric locomotive drew a train of 300 tons up the steepest gradient of 1 in 50; the radius of the sharpest curve was 985 feet. The speed of the goods trains was about 20 miles per hour. Experimental passenger-cars were being run in order to get the men thoroughly into the way of working what was to them a complicated system, before the full line was put into operation; and everything was

Mr. Hammond. working smoothly. The proposal of the Paper was to carry the sub-station on the car; that, of course, was a very attractive idea, but he feared the additional weight would kill it. He had ascertained what that additional weight would be; and taking an actual instance of a train weighing 126 tons, he found that the motor-equipment weighed about 10 tons, for a speed of 25 miles per hour. If the speed was 50 miles per hour it might be said with fairness that the weight of the equipment also would be twice as much, namely, 20 tons. The Authors calculated that the weight of the sub-station-equipment on the car would be twice the actual weight of the motors, which gave 40 tons. In a train weighing 126 tons, of which 20 tons was the actual weight of the motors, there was a useful weight of 106 tons; and if a further 40 tons was deducted there was a useful weight of only 66 tons compared with 106 tons, a difference of 40 per cent. He also feared that the Authors had overestimated the economy of working. Sub-stations required as much attention when in motion as when stationary; indeed, the wages of the men on moving sub-stations would probably be quite as high as, if not higher than, those on fixed sub-stations. He did not see where the economy of labour was to be realized; he was rather inclined to suppose that the result would be the opposite of what the Authors anticipated, because, to take the Valtellina line as an example, there were nine sub-stations, but there were many more than nine trains. By putting the sub-stations on the trains their number would be increased considerably.

Dr. Kennedy. Dr. ALEX. B. W. KENNEDY remarked that there was an old saying to the effect that it was not always possible to see the forest because of the trees that were in it, and he thought the discussion had suffered somewhat from a similar difficulty. The subject of the Paper was a large one, embracing many details, and so far the discussion had tended in the main to centre around certain details instead of around the chief subject. The electrification of main lines of railway was a new question, if indeed it was a question at all as yet; but in any case it was a question of the immediate future. It might be said that there were three ways of looking at it, the Paper dealing with only one. There was the question whether the change was desirable if it was practicable. That was a question of politics and finance, a very big question, and one on which he hoped a Paper, or Papers, would be read later on. Clearly, however, it was not the question discussed in the Paper under consideration. The second question—with which the Paper did deal—was whether the change was practicable if it was

desirable; in other words, assuming the desirability to be settled, were there any means by which the change could be properly brought about? Thirdly, there was the question of how the practicable scheme, if found, could be made mechanical by the working out of proper details. That was clearly not the subject of the Paper, and in spite of what had been said it could not be the subject of a Paper at the present stage. Engineers were not yet agreed, he thought, on what the practicable method of carrying out the change might be; and it was no use working out ornamental finials before a decision had been arrived at as to the sort of foundation that was to be put down. He had sufficient faith in his own profession to believe that if a practicable method could be found, and if that method was also found desirable, engineers would somehow or other find ways of carrying out the mechanical details. The question opened up by the Paper, and with which the discussion had really to deal, was the wide general question whether there was, or could be suggested, any system which was likely to be suitable for the working of main-line railways, supposing it were found desirable to work those lines electrically. He thought it must be admitted that the Authors had attacked the problem in a philosophical fashion. They had set out with no preconceived notion of a system, but with certain requirements which they believed to be necessary requirements for the change. They had not expressed even an opinion that the change was about to be made, whatever their private views on that subject might be. Assuming that the change might be considered desirable, they had tried to work out what requirements had to be met, and finally had tried to see how those requirements could be met. They might be quite right or quite wrong in their conclusions, but it must be admitted that the method they had adopted was the right one: not to say haphazard that A was the right method, or B, or C, or X; but to find out what the requirements of the case were, and then to see what method or combination of methods would meet those requirements. He hoped that the discussion would corroborate their conclusions or controvert them as being wrong; or would point out where their requirements were incorrect or inadequate; or would add other requirements to those which they had enumerated. If the discussion went along such lines, it was possible a very useful result might be attained. It was easy to say, of course, in reference to the proposed solution, that it had some obvious drawbacks, particularly the drawback of considerable weight and complication; and the Authors appeared to admit that freely. But, supposing that trains at the present time Dr. Kennedy.

Dr. Kennedy. were driven electrically, and that, the question of driving them by steam having been mooted, some one brought forward a locomotive and its tender weighing 80 tons or 90 tons, with a boiler, boiler-fittings, valves, valve-gear, and all sorts of machinery: might it not be legitimately said that it was heavy and complicated? He thought that would be a fair criticism, and it was exactly the same as the criticism brought against the introduction of electricity on main-line railways. The locomotive had been a great success, in spite of being heavy and complicated. He did not say that the Authors' solution was on all-fours with this example; but it was very inadequate criticism to object that in the result it was a heavy and complicated affair, because that description applied exactly to the thing that had been highly successful. Weight and complication were, no doubt, drawbacks as far as they went, and it was desirable to avoid them as much as possible; but the question which had to be dealt with was whether or not they had to be accepted, or to what extent they ought to be accepted, as essential to the proper solution of the problem. He gathered that the Authors maintained that there were compensating advantages, and, of course, that was a point which they had to prove, and which it was for the members to discuss. Perhaps, under the particular circumstances of its authorship, he was not called upon personally to express an opinion on the Paper, or even to say whether he agreed with the Authors or not. He would say, however, that when he had first seen the Paper in a much earlier stage, when in fact it had not contained much more than the general requirements which were laid down, he had warned the Authors that if the Paper were read at the Institution of Civil Engineers they would have a hornet's nest about their ears; because probably no one else had dealt with it in quite so exhaustive a fashion and no one else had arrived at the same conclusion; and so they would get no one whatever to agree with them. They seemed quite ready to fight their own battles, and appeared perfectly competent to do so. Without, however, going into criticism of the proposed system as a whole, he desired to speak especially on two points which formed an integral part of it, but which he thought had not been mentioned in the discussion. Both of those points had impressed him considerably from the point of view of working long-distance lines, from which point of view only he was speaking, and from which point of view only the Paper was written. The question of complication appeared to affect overhead work and conductors even more than it affected the moving machinery; because the overhead complications would be complications extending hundreds

Dr. Kennedy.

of miles in length, while those of the moving machinery were confined to a few square yards in a heavy frame. It would be quite bad enough—and he begged pardon of electricians for saying so—if one wire had to be put overhead carrying current at a high pressure; but it would be far worse if two wires had to be put up, and three wires would be still more objectionable. Therefore he thought the Authors were fairly entitled to say, and he entirely agreed with them, that they were justified in going even to considerable additional complication in the locomotive, if by doing so they could avoid the use of more than one overhead conductor. He did not believe that on long lines conductors at the level of the rails were likely to be used; but if it was desirable to avoid more than one overhead conductor at a high pressure, it was even more desirable to avoid more than one conductor at any considerable difference of pressure from earth, when that conductor was practically on the ground-level. That particular point raised the whole question of whether single-phase alternating currents were likely in future to be made available for such purposes as the Authors indicated. Personally, he believed that if their advantages were as great as they appeared to be, the difficulties in their use would be overcome. Much more difficult things than that had been done in the past 10 years, and the records of the Institution would show that things had been done which were not only more difficult but had been much more impossible-looking. From the point of view of long lines, he thought the second consideration which would justify complication was the adjustability of speed. He did not know what his railway friends would say to a proposal which involved all their locomotives running, under all circumstances and with all trains, at exactly the same speed, once they had started. He believed there were such things as gradients on railways, and his sensations told him that he generally travelled more slowly uphill than when going downhill, or running on the level; but he thought he was right in saying that if three-phase motors were used they must be run at practically a constant speed, and therefore must be powerful enough, unless some mechanical reducing-gear could be used, to take the heaviest train up the steepest gradient at that particular speed. If a more elastic system could be devised, giving the driver control over the speed of the train in the way he had control at present, it would be worth a good deal; and it was an arguable point that it might be worth quite as much complication as was proposed. Personally, he did not suppose that the precise system described by the Authors in the year 1902 was likely to be

Dr. Kennedy. carried out, because he did not think any main-line railway was likely to be electrified for a good many years. He was quite certain that in the years between 1902 and the first electrification on a large scale, more would become known about the matter, and changes and improvements would be made; and he thought the improvements would be much on the lines the Authors had indicated. Improvements were being made rapidly, and he had no doubt that the thorough ventilation of the subject which the Paper had brought about was one of the best things in the world to hasten forward those improvements. But whether the improvements followed the general lines indicated, or whether they followed some different line, he thought the members would all say—as he certainly said for himself—that they were really indebted to the Authors for the broad and scientific way in which they had treated the subject and brought it before the Institution.

Mr. Jenkin. Mr. C. F. Jenkin observed that he had been much surprised to hear so many electrical engineers state that they did not believe main lines were going to be driven electrically. He thought they were greatly mistaken, and he would even venture to differ from Dr. Kennedy's view that the main lines would not be electrified in the near future. He believed that in a few years a number of them would be using electricity, and those which were not doing so would be regretting it, because parallel electric lines would be taking their traffic from them. The present conditions of steam railways appeared to him to be the following. On all heavy trains there were two steam-locomotives, and there was talk of using three: these locomotives were of great weight, and had reciprocating parts. It was therefore impossible to get any large increase of speed, because the permanent way was not strong enough to stand it. Before more powerful engines could be used, the whole permanent way would have to be strengthened, at heavy expense; and in this respect the first great advantage of electrical driving was evident, namely, that it did away with the heavy locomotive, and distributed the driving power over as many axles as was necessary, thus allowing a large increase of speed—probably at least 50 per cent.—with the existing permanent way. By distributing the driving-power over a number of axles a much higher acceleration was obtained, as well as certainty of action; so that, whatever happened, the attainment of the required speed was perfectly certain, and was neither dependent on the power of the stoker to keep up the steam-pressure, nor affected by the state

of the rails. That fact would enable many more trains to be placed on the line, the trains running at shorter intervals than they did at present. The two advantages named would, he believed, enable railway companies to nearly double the capacity of their lines. That estimate was not a random one, but had been seriously put forward recently by the President of the Institution of Electrical Engineers. In order to take full advantage of electrical driving, railway engineers would have to re-model their method of dealing with the traffic: it was important they should realize that fact, and that those responsible for arranging methods for the electrical working of trains should realize it also. The ideal electric railway should be something like a bucket conveyor: instead of a few heavy trains at long intervals, there should be, at short intervals, a large number of small trains running at a high and almost uniform speed. The slow departure of the Scotch express from a London terminus was an imposing sight; but it was necessary to change all that, and to have three or four small trains departing as quickly as possible. It was useless to talk of putting an electric locomotive on a branch line to see whether it would do: such a method could give none of the advantages of electrical driving. Railway engineers had one excellent opportunity for testing those advantages. Many of the main lines had recently been doubled, and it was quite possible to convert one of the fast lines to electrical driving, putting all the troublesome trains on to the slow line. If that were done, there would be an opportunity of seeing what electrical driving would do, and the slow trains could be gradually transferred back again as methods were devised for dealing with them. If electrical working was coming at once, it was necessary to discuss and settle how it was to be carried out, and not to have another disastrous method of deciding such as had recently been seen in the arbitration court. It was for electrical engineers to settle the method of driving the trains, and not for arbitrators, who had really settled the question on the basis of the standard American motor at the time, and had taken that as the best. The result had been inevitable, but it was disastrous. Dr. Kennedy had referred to the fallacy of the question of relative weights, and he thought the argument was even more fallacious than that speaker had said. To say that, because the locomotive weighed 25 per cent., or 30 per cent., or even 60 per cent. of the weight of the rest of the train, its weight was ridiculous, really meant nothing. The same argument would prove that a horse was useless for carrying a soldier

Mr. Jenkin.

Mr. Jenkin. because it weighed 400 per cent. more than its rider. A more reasonable method was to compare the weight of a steam-locomotive with the weight of the electrical equipment for driving the same train; and if that were done it would be found that for existing trains the electrical equipment was slightly lighter. The example given by Mr. Siemens, in which a train ran at 20 miles per hour, and stopped every ½ mile, could not be dealt with at all by the steam-locomotive; and therefore it did not matter whether the electrical equipment weighed 60 per cent. or 80 per cent. of the weight of the train. The Authors mentioned as an advantage the fact that with the variable-ratio system the acceleration could be applied gradually, and he thought it was more of an advantage than they quite recognized. English engineers, borrowing from America, had the idea that passengers would only stand an acceleration of 2 or 3 feet per second per second, but he thought that was entirely a mistake. The height of the benches in the theatre of the Institution was about 32 inches, and if they were tipped back 1 inch at the top, and the members remained seated, leaning farther back, the forces on their bodies would be identical with those on a body undergoing an acceleration of 1 foot per second per second in a train. Tipping the benches back 2 inches would be equivalent to an acceleration of 2 feet per second per second, and so on. He thought no one would object to the back of his seat being tipped a couple of inches, and most would probably prefer it. What passengers would not stand was a suddenly-applied force of 15 lbs., which was equivalent to an acceleration of about 3 feet per second per second suddenly applied, so as to jerk their heads backwards; but if the acceleration was gradually applied, the body unconsciously adapted itself to the new conditions. In mathematical language, it was $\frac{d^3 s}{d t^3}$, and not $\frac{d^2 s}{d t^2}$, which affected the comfort of the passengers. The variable-ratio gear proposed in the Paper would enable large accelerations to be applied gradually, and without discomfort to the passengers, which was a matter of great importance, at all events for local trains.

Mr. Webb. Mr. F. W. Webb remarked that he would not have entered into the discussion but for the generally expressed desire that somebody should speak on the locomotive side of the question. Before going into any details, however, he desired to congratulate the Authors on the valuable Paper they had brought before the Institution, showing the various methods in use or suggested for transmitting energy to the electric locomotive. Some of the members

present must be aware of what had been done on the Orleans Railway, in connection with the extension of its main line from the old terminus to the Quai d'Orsay in Paris. All the trains on that extension, including heavy main-line trains, were worked electrically, most of the extension being in a covered way. In the discussion remarks had been made about the difficulty in picking up current where there were complicated cross-over roads and scissors-crossings; but on the Orleans line that had been overcome in a simple way, by putting a live rail in the roof of the covered way, corresponding with the various cross-over roads and scissors-crossings down below, and having a wiper on the top of the electric locomotive to take up current on that portion of the journey, instead of the live rail which ran alongside the running-rails of the other portion. The development of electrical traction on the metropolitan lines was being watched with a good deal of interest, and for such a service he had no doubt it would be found to be a great improvement upon the existing steam traction. It seemed almost a foregone conclusion that in a few years' time a great deal of the short suburban traffic would be worked electrically; but he did not think the time had yet come when the main traffic of such a line as the London and North Western Railway could be worked electrically instead of by the steam-locomotive; nor did he believe that in large shunting-yards, such as were now being developed at Crewe and elsewhere, electrical traction could compete with the present method of shunting by steam-locomotives. At the Crewe yard there were more than 50 miles of shunting-sidings, which, with the present means at disposal for doing the work electrically, would require either a live rail or other conductor of equal length. He would like to see how his electrical friends would contrive to install an overhead conductor or a live rail to work those sidings. A live rail at the ground-level would make the yard an exciting place for the shunters to work in at night; and an overhead wire would mean 50 miles of conductor on a length of 4 miles of railway. To give an idea of what electrical engineers would have to do to work the North Western line alone, he would mention that during the past 12 months the engine-mileage had been 73,372,388 miles, or $2\frac{1}{3}$ miles run every second, which was equal to between eight and nine journeys round the world every 24 hours; and when he mentioned that the engines could run a distance equal to about two-and-a-half times the circumference of the earth without a single failure, it would be seen that the steam-locomotive was not so complicated and unreliable as Dr. Mr. Webb.

Mr. Webb. Kennedy's remarks would indicate. He was satisfied that such a system as was shown in *Fig. 9* would not work successfully, and should not for a moment be considered. On the London and North Western Railway, including shunting- and other engines, there were 3,002 locomotives, and from the mileage he had given it would be seen that the average distance run by each engine per week was about 500 miles. If a system like that shown in *Fig. 9* were adopted, at least 3,000 such machines would be required, even supposing that the electric locomotive could work the passenger trains now running, some of which weighed over 350 tons and travelled the whole length of the line from London to Carlisle, a distance of 300 miles, at 50 miles to 60 miles per hour, and often at a much higher speed, with only one stop. He had yet to see an electrical contact system which would stand wear and tear at anything like the speed, especially in going through such complicated stations as Crewe, Preston and Carlisle. It would be remembered that, on the occasion of the Engineering Conference of the Institution in 1899, he had run a special train on the 8th June from London to Crewe and back, to show the best work then possible with compound engines. He had been able on that occasion to show that, in moving the train, 716 feet in length, consisting of fourteen vehicles, weighing 420¼ tons including engine, tender and passengers, and travelling at the average speed of 50 miles per hour for the down journey and 52·4 miles for the return journey, the run had been accomplished on a consumption of 1·58 ounce of coal per ton per mile: and the small piece of coal in his hand represented that quantity. On another occasion he had had a careful experiment tried between a compound and a non-compound heavy mineral engine, moving trains of equal weight, namely, 770 tons, at an average speed of about 18 miles per hour; and the best result he had been able to get then with a compound engine had been a consumption of 0·969 ounce of coal per ton per mile, at the speed named. The other piece of coal in his hand represented that. Further, before it became possible to do electrically such work as he had indicated, it would be necessary to save, in addition to working-expenses, a sum that would be sufficient to replace the present locomotive stock on such a line as the London and North Western Railway, which he estimated to be of the value of £7,000,000, and which would simply become scrap if it had to be replaced by electrical plant. It would also be necessary to provide, for the electrical plant that would be required to take the place of the steam-locomotives, a sum which he thought

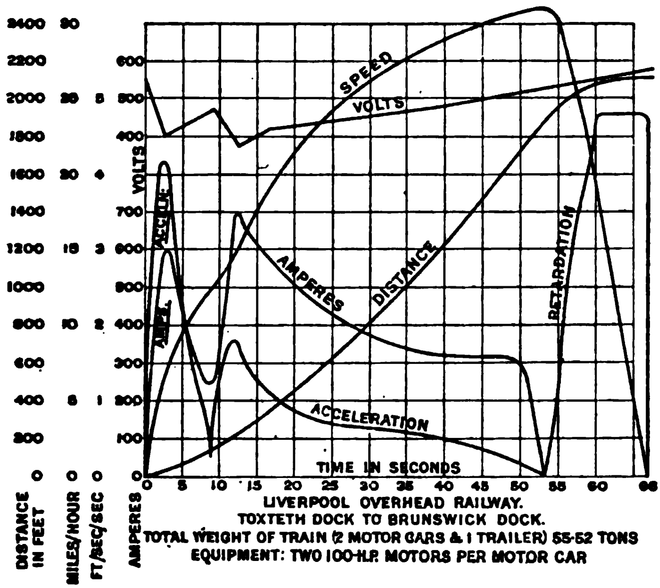
would be not less than the figure he had mentioned, and possibly, he had been told, twice that amount. The interest on between £14,000,000 and £20,000,000 of capital would therefore have to be earned before any saving for the shareholders could be effected by substituting electricity for steam-power. Although all were anxious to see electricity developed for working suburban traffic, he did not think there were many present who would see the whole of such a line as the North Western worked electrically; at all events, not until some simpler means of dealing with the question was arrived at than had been shown in the Paper, by making the electric motor self-contained, or until another Marconi arose to enable current to be collected without making physical contact with a conductor. Mr. Webb.

Mr. J. Holden expressed surprise at what appeared to him to be the somewhat academical nature of many of the remarks that had been made, which appeared to indicate that some of the speakers were not acquainted with the actual conditions of the ordinary working of a main line of railway. He did not see how it would be practicable, by means of locomotives, to work electrically, on a main line, goods trains in which sometimes the majority of the wagons were owned by private individuals and not by railway companies, unless very small trains were worked, which would be difficult to deal with on an already congested railway. If the work was to be done, as had been suggested, on the multiple-unit method, then some means would have to be devised for fitting every one of the private owners' wagons, as well as the railway wagons, with wires for the purpose, and it seemed that would be difficult to do. Even if it could be done at all, there were strong reasons, as Mr. Webb had forcibly pointed out, for doubting whether it could be done economically. Main-line working was now carried out by more or less heavy trains, the weight of which had a steady tendency to increase. For instance, the Great Eastern Railway had recently been putting on locomotives to haul fifty 10-ton coal-wagons instead of thirty-five, and to run between Peterborough and London in an hour less time than formerly; and he thought that was the direction in which most railways had recently been working. Those trains had to be run at comparatively long intervals, and sometimes under difficult conditions. Notice would be given that within a short period preparation had to be made to accept, say, at Peterborough, as many as twenty to thirty coal-trains; and those trains had to be taken. That would throw a severe strain upon any electrical method of propulsion. It was desirable Mr. Holden.

Mr. Holden. not to have more trains than were absolutely necessary, so as to work the coal-trains in between the passenger and goods traffic, and consequently it was desired to have as many wagons as possible on each train. In addition to that, the fewer the trains the less they cost for drivers', firemen's and guards' wages. That appeared to him to be the first condition. For economy of electrical working—which he might call the second condition—it seemed to him to be necessary that the load on the generating-station and on the plant in general should be kept as uniform as possible, so that a high load-factor might be obtained. These two conditions were absolutely inconsistent one with the other; for in order to fulfil the second condition it was necessary to divide the long trains into a large number of short trains, each of which would have to be worked at considerable expense for the wages of drivers, guards, and attendants. Into the question of conveying the current he would not enter. His electrical knowledge was not very profound, but it seemed to him that little or no demand existed for electrical traction on main lines. It was quite a different thing with suburban traffic, worked by a large number of trains running at short intervals. On some portions of the Great Eastern Railway suburban trains were running throughout the whole 24 hours, and in connection with such traffic there seemed to be a great deal to be said in favour of electrical traction on the multiple-unit system. Already on the Enfield line there were trains which weighed altogether about 200 tons, and were worked by steam-locomotives with an acceleration of 29·7 feet per second, equal to over 20 miles per hour, in 30 seconds; and that, he ventured to think, was equal to, if not higher than, any acceleration to be found on other steam-worked lines in the country. But it had been necessary recently to increase the capacity of the line by widening the carriages, so as to make them carry about 22 per cent. more passengers; and although that had been in operation for little more than 2 years the increased capacity had almost been overtaken. Under such circumstances it seemed that the increased acceleration obtainable with an electric line would be very valuable. If in 30 seconds an acceleration of 30 miles per hour was obtained instead of 20 miles per hour, it would be of great advantage; but there were considerable difficulties to be overcome. The attention of electrical engineers might with much greater advantage be directed to the perfecting of the economical conversion of suburban systems, than be occupied in anticipating the possible conversion of main lines for long-distance traffic.

Mr. S. B. Cottrell believed that, as a considerable amount of attention had been drawn to rapid acceleration, some recent results attained on the Liverpool Overhead Railway might be of interest. The trials had been so satisfactory that the Company had determined to provide all its trains with the rapid-acceleration equipment. The curves in *Fig. 10* illustrated the acceleration, speed, retardation, and power-consumption of the experimental three-coach train during a series of runs: those of *Fig. 11* illustrated the speed, horizontal effort, efficiency, and horse-power of a 100-HP. motor, four of which were used to work the train. Mr. Cottrell.

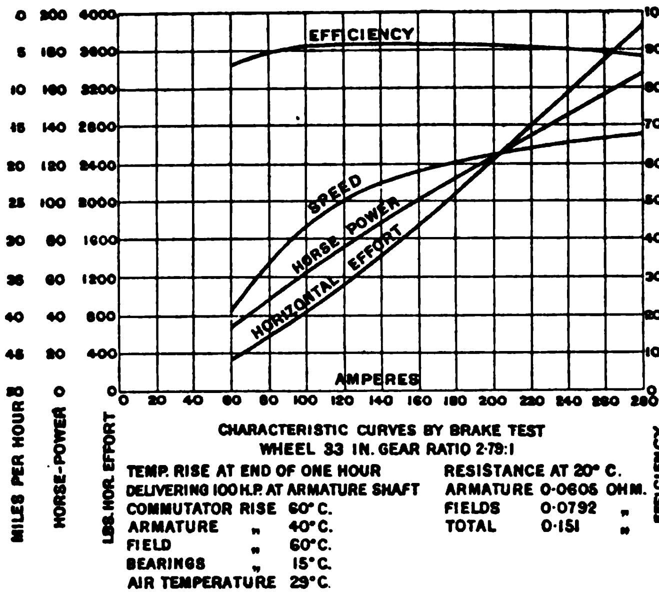
Fig. 10.



The distance on which the actual curves had been taken was 2,110 feet. The total length of the Overhead Railway was 6½ miles, and at the present time, with seventeen stations, involving fifteen intermediate stops, averaging 11 seconds each, the time occupied on the journey was 32 minutes. With the accelerated service, allowing the same time at each station, it would be possible to reduce that to 20·4 minutes; thereby increasing the scheduled speed from 12½ miles to nearly 19 miles per hour. The total weight of the particular train tested was 46·3 tons, the carrying-capacity being 154 passengers; fully loaded the train would weigh nearly 56 tons. It would be seen from *Fig. 10* that the

Mr. Cottrell. acceleration obtained with this train had reached a maximum of over 4 feet per second per second, a higher acceleration than that which Mr. Holden had suggested as desirable on suburban lines. The average acceleration was about 3 feet per second per second. The retardation with the Westinghouse quick-acting brake was also satisfactory, as it was well up to 4·8 feet per second per second. These figures were interesting as being the results of actual independent tests, the curves having been taken by Mr. A. Mallock with his recording instrument, and being therefore free from any personal element. With regard to the power-con-

Fig. 11.



sumption, trains running at a high scheduled speed, and stopping frequently, such as the figures applied to, would take between 120 watts and 150 watts per ton-mile. If the distance between the stops was increased that would diminish to 90 watts or 100 watts per ton-mile. In the actual train to which he referred, the power was 137 watts per ton-mile, or 6·35 kilowatts per train-mile. He estimated that the total cost of producing and transmitting the power to the trains was 3*d.* per train-mile, that figure being based on present experience. From *Fig. 11* it would be seen that the efficiency of the motor was highly satisfactory, reaching 93 per cent.

at the full load of 100 HP. The current-consumption with that output was 160 amperes at 500 volts. Of course under variable conditions the motors sometimes had to take a considerably higher current than 160 amperes, and they would stand an overload of 100 per cent. for a short period without undue sparking or rise in temperature. Another satisfactory feature of the motor was that its weight was only 42 lbs. per horse-power. The weight of a motor per horse-power was of great importance when running a service of trains at very short intervals. Another fact in which pleasure was taken in Liverpool was that in spite of the wave of Americanism passing over the country, the English Electric Manufacturing Company of Preston had been successful in obtaining the contract for the equipment of the entire rolling stock through the agency of Messrs. Dick, Kerr & Co. The particular motors to which he had called attention had been designed to the Company's specification to meet their requirements, by Mr. Sidney Short of the English Manufacturing Company, and in all the trials it had entirely fulfilled the specification. Mr. Cottrell.

Mr. Horace Bell remarked that in the presence of those whom he might call the high-priests of steam-locomotion and electric traction, he felt some diffidence in bringing forward one particular aspect of the question under discussion. It had been fairly established, he thought, by previous speakers that the difficulties of installing electrical traction on long lines of railway were far from being solved; and it had been equally well established that in order to ensure fiscal success in the application of electrical traction on any line of railway it was necessary to have a heavy traffic and a frequent service. Colonel Crompton had put forward as an instance a line of railway in the Himalayas with which he was concerned, and Mr. Bell hoped that it would not be indiscreet on his part to say that he presumed Colonel Crompton referred to a projected line of railway from the Plains of India to Kashmir. The length of that line was between 160 and 180 miles, and it ran through difficult country. The gauge was assumed to be 2 feet 6 inches and there were two summits, both with long tunnels—one 10 miles in length—at altitudes 6,000 feet and 8,000 feet respectively above mean sea-level. There were long reverse gradients, and a ruling gradient of 1 in 20; and it was proposed to adopt electrical traction. The idea of working the line electrically was due to the very competent and accomplished young engineer who had first taken the particular project in hand, and who had been much impressed in favour of electricity, and naturally so, by finding that there was a vast Mr. Bell.

Mr. Bell. amount of water-power available in the valleys: he had at once arrived at the conclusion that there at all events was a case where electrical traction was a necessity. Applying the canon which had been laid down by several speakers, particularly by Mr. Siemens, that electrical working could be fiscally successful only in the face of heavy and frequent traffic, it would be useful to see what had to be dealt with on the line which Colonel Crompton had put forward as a suitable one for electrical traction. He would use the figures of the estimate: he did not know whether that estimate was sufficient or not, but personally he thought it was insufficient. The cost was estimated to be, in round figures, under £1,000,000. The cost of the electrical installation and water-power stations, excluding rolling stock other than locomotives, was put at £433,000. The maximum goods traffic on the railway was estimated at 75,000 tons per annum, and passengers of all classes at 150,000; that was, about 200 tons of goods and 400 passengers per day, in both directions. On that basis he estimated that the engine-mileage might be taken at 395,000 miles. Therefore ten, or, say, a dozen, steam-locomotives, of which he was the humble devotee at present, would work the whole of the traffic; and the coal-bill, at the maximum rate assumed in the estimate, which was considerably under £2 per ton, would be about £13,000 annually. Capitalizing the amount of the coal-bill at 5 per cent., it appeared that the utmost that could be spent on electric traction would be £250,000, as against the estimate of £433,000. But it was necessary to take into account also the extra cost of establishment at the power-stations in addition to the driving equipment (whether the latter consisted of electric motors or steam-locomotives), maintenance, breakdowns, and snowdrifts—because the line passed through difficult snow ranges—and the general factor, which was more or less considerable, of danger from electric contact. In fact, as far as he could make out in that particular instance, it would seem that steam traction would be infinitely cheaper and preferable under the circumstances. He would pass over the question whether the line would ever be made, or whether, if made, it would be on that route or on another route altogether; and he could well excuse the electrical engineer, as he would an engineer in his own branch of work, for trying to gather in the harvest wherever it might be found: but it was essentially necessary, if the question of electrical traction on railways was to be considered, to bear in mind that the first thing to discover was not whether it was possible as technical work, but whether it would pay.

Mr. E. W. Moir considered that the question of steam haulage versus any system of electrical traction was really one of costs, and in order to arrive at a comparison of the cost of electrical and of steam haulage, the point to be considered was the value in coal of 1 horse-power at the tire on the rail. He had been examining some records of the amount of coal burned by locomotives, and had found, in a Paper[1] by Messrs. Adams and Pettigrew, that an express locomotive tested by them had burned only 2½ lbs. of coal per indicated horse-power-hour. That was a remarkably good result, and a much better one than would have been expected; in fact, it would compare very favourably with, and might surpass, the results of an ordinary generating-station with a small load-factor. Again, the locomotive in question had produced 8¾ lbs. of steam per pound of coal, which was a very good result, and one difficult to beat in any generating-station. The results were so good, however, that he had referred to other sources of information, and had found in a Paper[2] by Mr. Walter Smith, of the North Eastern Railway, that the coal burned by locomotives he had tested had been 3½ lbs. per indicated horse-power-hour, and the steam used 26 lbs. per indicated horse-power-hour. Those figures would be more in line with what would be expected, the other example being an exceptionally good result. He had confirmed his view by other records, and had taken Mr. Smith's figures in the conclusions he had come to, as being probably nearer the mark. There was little doubt that modern triple-expansion high-speed engines, such as were now built to perfection by many makers in England, could be run at full load on between 16 lbs. and 17 lbs. of steam per indicated horse-power-hour, which showed, roughly, a saving of 33⅓ per cent. over the coal-consumption of a steam-locomotive. If, then, a modern high-speed triple-expansion engine could be put on a truck and run as part of the train, somewhat on the lines of the Heilmann locomotive, he thought there was room for economy between the 33⅓ per cent. saving in fuel, and a possible loss of 15 per cent. in the conversion of energy between the generator and the motor on the wheels. Such a train would be fitted with motors on the multiple-unit system, from which the advantage of rapid acceleration, already pointed out, would be gained, and reciprocating parts would be done away with. He thought the wear and tear would undoubtedly be less for passenger traffic, the cost of main- Mr. Moir.

[1] Minutes of Proceedings Inst. C.E., vol. cxxv. p. 282.
[2] Proceedings Institution of Mechanical Engineers, 1898, p. 605.

Mr. Moir.

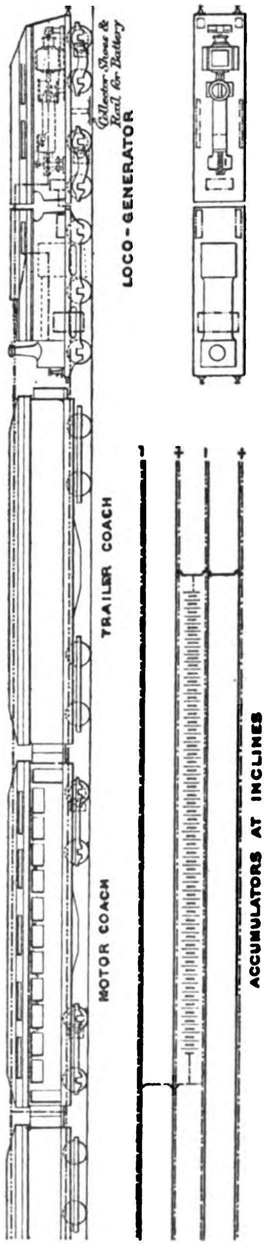


Fig. 12.

tenance of the boilers would be reduced, and the design of the boilers could be modified to make them more easily cleaned and possibly more efficient. The point of greatest importance, however, in obtaining economy, would be to keep the high-speed engines running with a high load-factor. That was the difficulty with the ordinary locomotive; it had to be powerful enough to mount steep gradients, and did no work at all in running downhill. He suggested that, in order to ensure the engine running at full load-factor all the time, it was possible to have a third conducting rail at stations and on steep gradients and inclines, so that when the train stopped the engine might continue to run, sending current through the third rail to a storage-battery in the station, which would store the current ready to assist in starting a train and in lighting the station (*Fig. 12*). On steep inclines a similar method of working could be adopted; the engine when running down the incline could be paying into the third-rail system current which could be stored in a storage-battery not requiring much attention; and that current could be utilized for assisting a train running up the hill. The carrying of the generator on the train was no new idea; but he was not aware whether the plan mentioned had been suggested previously as a possible means of maintaining a high-load factor. If that could be done, the

high-speed engines would certainly show better results than the locomotive in coal-consumption. The third-rail equipment could be used for absorbing the energy recovered in braking. Where electrical haulage was most likely to gain over any other system was in returning energy to the line when braking was required, or when the trains were running down steep gradients. Such a third-rail system would be a means of introducing electrical traction tentatively, combining it at first with the use of ordinary steam-locomotives, without the expenditure of £20,000,000 to which Mr. Webb had alluded. The trains could be fitted up and introduced gradually, and the storage-batteries could be added to as the number of trains driven electrically was increased. Were such a system introduced, the trouble of steep gradients would be obviated to a large extent. If a train running downhill and storing energy could help to pull another train up the incline it would be an immense advantage, for lines could be laid out with steeper gradients, and therefore be constructed much more cheaply. Mr. Moir.

Sir Douglas Fox, Past-President, considered that, among the many reasons why the thanks of the Institution were due to the Authors for bringing the Paper forward, one very important reason was that it emphasized the much closer relations which were becoming established between the practical engineer and the electrician. As he reflected upon the history of the matter in England one or two sad remembrances rose up before him. His memory took him back some 30 years, a long time in the history of electricity, to discussions which his friends Sir James Brunlees and Sir William Siemens had had with him, as to whether it was not even then possible to electrify the Mersey Railway. There could be no doubt that if Sir William's lamented death had not intervened, he would have entered into a contract at that early date, and would have carried it out effectually. Now, after the expiration of that long period, the railway was about to be electrified by the British Westinghouse Company. In consequence of Sir William's death, the great honour of introducing electrical traction into England had fallen to the lot of the late Mr. J. H. Greathead, M. Inst. C.E., aided by Sir Benjamin Baker, Past-President. That first electric railway—the City and South London line—had been followed soon after by another enterprise, of which something had already been heard in the discussion, and in which Mr. Greathead had been associated with himself, namely, the Liverpool Overhead Railway. About that railway he would only mention that it had worked very successfully from an electrical Sir Douglas Fox.

Sir Douglas Fox. point of view, and also commercially, which was, after all, most important. While those who had had to do with the origination of the line must derive satisfaction from the fact that it had worked so well, the credit for its success depended almost entirely upon the earnest and energetic way in which Mr. Cottrell had carried on the management. The increased acceleration which Mr. Cottrell had succeeded in introducing constituted an important step in advance. Looking at it from the constructive engineer's point of view, it was interesting to find that the rolling load, so far as its effect on the structures was concerned, had not been increased. Since the opening of the Liverpool Overhead Railway, engineers had been brought more and more closely into touch with electricians. They had to thank electricians for the telegraph and the telephone, and for the automatic signals, which were used at Liverpool, and which, if properly adapted, might be of greater use in the future; but they had still more to thank electricians for bringing to their aid the important power of electrical traction. A great deal had been heard lately about the electrical working of underground railways in London; and the discussions which had taken place between two not very friendly companies, as to the best means of electrifying the "Inner Circle" traffic, had been followed with interest. Previously to the arbitration on that question, he himself, in the early part of 1901, had had to decide a similar question in reference to the Great Northern and City (underground) Railway; and, after considering tenders from all the leading British, German, and American firms, he had come to the conclusion that continuous current of moderate voltage, with insulated returns, should be adopted. It was evident that the time was not ripe for introducing into "tubes," high-tension alternating currents, there being risks connected with them that many engineers were not prepared to face; and, whatever might be possible in the near future, he was well satisfied with the system of continuous current, transmitted either directly from the generating-station on short lines, or by high-tension alternating current to sub-stations on longer lines. He thought it might be said that for "tubes" electrical traction had become a necessity, and he believed it would soon be equally so for suburban lines, particularly where the electrical traffic could be intermixed with the steam traffic. That had already been done on the line between Varese and Milan. There the electrical traffic was carried right into a busy terminus, the conductors being ingeniously placed under a slight projection at the edge of the platform; and the electric train worked quite harmoniously among the steam-driven trains it was trying to supersede. He thought some-

thing of that kind must come rapidly in the suburbs of the great cities of the kingdom; and the sooner railway companies realized that fact the less would they be injured by what would certainly happen if they did not realize it, namely, the introduction of suburban electric lines to compete with them. He thought also the time was coming when there would be high-speed electric railways. He did not believe that, for the purpose of such lines, it was necessary to have recourse either to a line of no gauge at all—the "mono-rail"—or to the line which was seriously proposed in Austria and defended by abstruse mathematics, with a 12-foot gauge and an engine of unknown weight. He believed that neither of those expedients was necessary, and that it was quite possible, when circumstances permitted and traffic was available, to introduce rapid transit in England or in any other country, without departing from the existing 4-foot 8½-inch gauge. But when considering the question which formed the chief subject of the Paper, namely, the introduction of electrical traction into the working of existing main lines, he did not see how he could add anything to what had been said by Mr. Webb, who was *facile princeps* in anything having to do with such railways. He did not think that those who proposed that step realized the complications which would have to be dealt with. On an express line with frequent passenger trains only, the thing might be accomplished; but he did not know how any such system as that under discussion was to be introduced on an important main line, with its complicated sidings, fast and slow passenger traffic, special trains at unknown intervals, goods trains, and mineral trains; the problem appeared to him at present to be quite insoluble. Electricians deserved thanks for the rate at which they had been progressing in the study of the problems of electrical traction, but he felt that there was still much to be done in perfecting the working of underground railways, in working suburban lines, and in dealing specially with cases, such as were to be found in many parts of the world, and with some of which he was concerned himself, where good water-power could be obtained, than in the serious and almost impossible task of electrifying the main lines of England. Electricity had undoubtedly great advantages, but it seemed to him that its main point, so far as its application to high-speed traffic was concerned, was that it did away with reciprocating action. By the skill, trouble and care bestowed upon it, the locomotive had been brought to its present perfection and was no longer a complicated machine but a simple and thoroughly efficient one, especially in regard to the consumption of coal; nevertheless, it did seem as if the limit of Sir Douglas Fox.

Sir Douglas Fox. speed was fast being reached. On a line with which he had to do, the trains sometimes travelled at 80 miles per hour, which was a very high speed where there was reciprocating action. If a much higher speed was to be attempted, then the great advantage of electricity would appear and its opportunity would come. At present, so far as he could see—and he had carefully watched what had been going on—it seemed that electricians could best use their opportunity of working lines where there was a heavy and constant traffic with short intervals between trains, and where, therefore, they could count on something like a uniform load. One other matter he wished to refer to was the introduction of high-tension currents in overhead conductors, more particularly in tunnels; and he thought that practice was attended by great risks. In America it had already been found in the Baltimore and Ohio Railway tunnel that it was not safe to have even a single overhead wire at moderate tension. The overhead wire itself had been found to be a source of great trouble; and he was confident many difficulties would be met with in attempting to use overhead wires in tunnels with such a pressure as, say, 3,000 volts. The experience of the conductor-rails on the Liverpool Overhead Railway had been satisfactory, and they showed little sign of wear. He thoroughly endorsed what had been said by Mr. Webb and others as to the practical impossibility of using overhead wires in large sorting-sidings, such as those at Crewe; but no doubt electricians would find a better plan of dealing with the conductors. Whatever the system, it must avoid danger to platelayers, and must deal effectively with cross-over roads. Until a better mode of collecting the current was devised, and until overhead wires could be superseded, it was practically impossible, in his opinion, to introduce electricity into such a complicated system as that of the London and North Western Railway, the Great Western Railway, or any of the other great railways of England. He considered it highly important, in designing electric plant, to concentrate heavy parts in the central station and to keep any machinery upon the train as simple and as light as possible.

Mr. Brown. Mr. C. S. Vesey Brown admitted, in reference to the opinion expressed by several speakers that the question of the adoption of electrical traction on main-line railways was not yet ripe for consideration, that the difficulties mentioned by Mr. Webb, Sir Douglas Fox, and others were almost insurmountable with the existing knowledge; but 10 or 15 years ago there had been many difficulties in the introduction of electric power and

electric lighting all over the country. Financial questions were the main point of the whole business—the question, would the introduction of electrical traction on the main lines pay? Ten or 15 years ago the same question had been asked on the introduction of electric power and lighting. It had been practically answered by the enormous development which had taken place in electric lighting and power-supply. Railway traction had reached its state of perfection owing to the requirements of the public. The growth of the passenger traffic had called for longer trains, heavier locomotives and carriages, stronger permanent way, bridges, etc. The same was the case with the goods traffic. In the Newcastle-on-Tyne district might be seen trains of fifty trucks, carrying 10 tons of coal per truck, drawn by a single engine, because the coal had to be got away in the shortest possible time, and so far no plan but increasing the power and the weight of the locomotive had presented itself as a solution of the problem. The Authors had submitted, perhaps a little before its time, a scheme which enabled the question to be considered along with the development of the large electric-power schemes which were attracting a considerable amount of attention. Those who had to deal with large central stations for electric power-supply would undoubtedly be the first to be asked to supply power to the great railways; and in dealing with the matter they would have to be careful not to fall into what might be called the "standard" that had been set by the Central London Railway. He did not believe that that system was one which could allow of development, or which could be used in the complex crossings and junctions met with all over the country. He was certain that the suggestion of the Authors for single-phase transmission, on the lines laid down in *Fig. 9*, was the right one. Any one who had had to use single-phase alternators or single-phase synchronous motors, knew that once they were got into step, and were running as they should run, there was nothing to beat them. A great deal of trouble had to be taken to perfect them; but when once an alternating-current motor was synchronized with its generator, there was nothing that could beat it. The collection of the current could hardly be by overhead wires, first, because the height of the trolley-pole, or whatever other method of carrying the overhead conductor was adopted, was bound to vary greatly, owing to bridges and tunnels coming in the way; and secondly, because of the action of thunder-storms. Very few people knew what was the effect of lightning striking a high-tension overhead wire, but they had only to see the effect once in order to appreciate it fully. With regard to the collection Mr. Brown.

Mr. Brown. of the current, he suggested that a channel-bar turned on its narrowest side, and securely covered, in the 6-foot way, would meet the case.

Sir William Preece. Sir WILLIAM PREECE, K.C.B., Past-President, remarked that he purposed dealing with the question of electrical traction, so ably and clearly brought forward in the Paper, from the point of view of the railway man rather than from that of an electrical engineer. Fifteen years of the early part of his professional career had been spent upon railways, and he had fortunately been able to take part in the introduction of every single practical application of electricity to their working. His first job, in 1853, under the late Mr. Edwin Clark, M. Inst. C.E., had been the establishment on the London and North Western Railway of the permissive block system. Therefore he claimed to look at the matter from a railway point of view. It was a railway traffic-manager's question. If electricians could not demonstrate to a general manager that electrical traction would increase the carrying-capacity of his line, and diminish the working-expenses, there was not the slightest use in going to that manager or to a railway board with any attempt to advocate electrical traction. Every one connected with railways had learned a new lesson, almost a new philosophy, in the great object-lesson of tramway-working, which had shown that, to extract profits from a railway, it must be worked on the principles of rapid transit, cheap fares, and frequent service. A large number of light trains brought in more money than a few heavy trains. He had not yet found that any railway company in the country had taken kindly to the development of light railways and tramways, which had originally been intended to be feeders to the larger lines. On the other hand, wherever the Railway Commissioners went to look into the merits of light railways, whenever tramway companies went before Parliamentary Committees in an endeavour to develop the tramway systems of the country, they were always opposed by railway companies, who thought they saw competition in what were really nothing but feeders to their own systems. A great engineer, serving a great company—no less a person than Mr. Webb—had remarked that the locomotives under his charge were worth £7,000,000, and had asked whether it was thought that the London and North Western Railway Company would be prepared to scrap £7,000,000 worth of steel, brass, paint and varnish. But if Sir William Preece were to submit to the directors of that Company a proposal showing that he could carry twice as many passengers at half the price, they

Sir William Preece.

would scrap those locomotives at once, and Mr. Webb himself would be the first to approve of that course. No man deserved the encouragement and the support of electrical engineers more than did Mr. Webb; there was no object-lesson in the country so strong as Crewe itself, where Mr. Webb, the "king" of Crewe, had applied electricity to every conceivable purpose, except to move his coaches among the 50 miles of siding. Nobody would more heartily assist in the introduction of electrical traction, if it was possible to show that it would double the receipts and halve the expenses, than would Mr. Webb. Was there anybody who would hesitate? He would not attempt to prove there was not—he could not go so far; what he desired to show was that the whole secret of the introduction of electrical traction was to prove that the capacity of the line for traffic could be increased, and the working-expenses be reduced. As an example, he would take an instance of a line on which working by steam-locomotives had reached its climax. Steam could do no more on the Metropolitan and Metropolitan District railways than it had done already; but Sir John Wolfe Barry and he had had no great difficulty in showing the Boards of those railways that the introduction of electrical working would mean an increase of 35 per cent. in the carrying-capacity of their line, and that the working-expenses would be diminished. The time now occupied by a train in going around the "Inner Circle" was 70 minutes; with electrical traction it would be simplicity itself to do that journey in 50 minutes. The Metropolitan Railway differed from the London and North Western Railway in the fact that on the former line each train was continually starting, coasting and stopping, while on the latter, after getting up full speed, the train could run at this speed the whole distance, practically from London to Carlisle. On the Metropolitan Railway full speed was never even attained. The ordinary acceleration on a steam railway was about 6 inches per second per second, a figure found by careful tests on the Metropolitan Railway and generally accepted, although Mr. Holden had pointed out that with certain engines he had succeeded in reaching a speed of 20 miles per hour in 30 seconds, which meant an acceleration of 1 foot per second per second. On the Metropolitan Railway there was no difficulty in getting, by electrical traction, an acceleration of 1½ foot per second per second, which meant 20 miles per hour in 20 seconds. The members had had one of the best object-lessons it was possible to have, in the facts about the new motors of the Liverpool Overhead Railway which Mr. Cottrell had given in a quiet, unassuming way

Sir William Preece. —a lesson which must have considerably enlarged the ideas of the members as to the value of electricity. Mr. Cottrell had shown that instead of doing what engineers had been proud of a few years ago, getting a speed of 20 miles per hour in 20 seconds, he had got 20 miles per hour in 10 seconds; and the acceleration, instead of being 6 inches per second per second, as it was on most of the steam lines, was 3 feet per second per second. There was a prevailing idea that a rapid increase of speed such as that would dislocate the necks of passengers or at least make them very uncomfortable; but the fallacy of that notion had never been better illustrated than by Sir Frederick Bramwell, before the Committee of the House of Commons on the Liverpool and Manchester high-speed railway, when he had instanced the case of a swing, which had a greater acceleration than any of those mentioned. There was absolutely no difficulty in getting an acceleration of 3 feet per second per second, and such acceleration did not entail discomfort to the passengers. On the other hand, it had enabled Mr. Cottrell to increase the mean speed of his trains. The Liverpool Overhead Railway had been opened in 1893, in the early days of electrical traction, but the speed of working had been so far improved that the period of running of a train from one end of the line to the other had been reduced from 32 minutes to 20·4 minutes, a reduction of one-third. On the Metropolitan Railway, a congested line where the trains were always starting or stopping, the mean speed was only 11 miles per hour; while the speed on the London and North Western Railway rose to 60 miles, and often to 80 miles, per hour. Electricity would improve the 11 miles per hour of the Metropolitan Railway to 15 miles per hour. On the Liverpool Overhead line the mean speed was to be increased from 12½ miles to 19 miles per hour. He considered therefore that he had established his first point—that electrical traction increased the capacity of a line which was considerably congested. With regard to working-expenses, a striking illustration had been given by Mr. Webb, who had exhibited a lump of coal, weighing 1·58 ounce, as the amount of coal required per ton-mile in an express train running at 51 miles per hour. It was extremely interesting to know that that piece of coal would haul 1 ton over 1 mile; but who understood what a ton-mile meant? He did not think even Sir Frederick Bramwell knew that. What it was important to know was—how many pounds of coal per horse-power-hour it represented. Mr. Holden might have shown in a little flask the amount of oil which would have done the same work; and he hoped that the fact of his not

having done so was not to be taken as indicating that the use of oil had been a failure on the Great Eastern Railway, because engineers were looking forward to the introduction of oil as a fuel. If Mr. Holden had brought his oil it would have had about half the volume of Mr. Webb's coal, but it would have meant no more. The piece of coal shown by Mr. Webb really meant that on the engine to which he had referred the consumption of coal per horse-power-hour was 3·7 lbs. for that particular run; but every locomotive engineer was prepared to acknowledge that 6 lbs. per horse-power-hour was a fair allowance for all standing and running charges. All calculations of horse-power and of steam expended on railways were inaccurate, and were not to be compared with the accuracy of the measurements of the amount of electrical energy expended in working trains. Mr. Cottrell had stated that it required 6·25 kilowatt-hours, or Board-of-Trade units, per train-mile, on his trains weighing about 50 tons and carrying 154 passengers; and that was something tangible. Nearly all over the country large power-companies could be found to deliver power to a railway company, or to works of any kind, at a cost of 1*d.* per Board-of-Trade unit; which meant that power for working a railway could be obtained at a rate which would make locomotive hauling-charges 6¼*d.* per train-mile. Sir William Preece.

Mr. Webb asked at what speed.

Sir William Preece said 120 miles per hour if necessary.

Mr. Webb remarked that he had mentioned 50 miles per hour.

Sir William Preece thought it was not necessary to be particular about speed. Mr. Cottrell had spoken of only 18 miles or 19 miles per hour and had said that his working-expenses were 3*d.* per train-mile. It was a step in advance to be able to say that a railway could be worked at 3*d.* per train-mile. The next point to which he wished to draw attention was the reduction of the rolling load gained by introducing electrical traction. It was necessary to draw a clear distinction between dead weight and paying weight. There was something wrong in the system on which railway accounts were made out. A "train-mile" or a "ton-mile" meant very little; what it was necessary to know was, how much would a ton of coal bring in, in pounds, shillings, and pence? If it was not possible to show that with electrical working it would bring in more than with steam, electricians must be silent. He had found it could be said that as a rule on railways for every ton of load one passenger could be carried; but on electric lines it would be found that every ton meant three passengers. Supposing that electricity and steam were on the same

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footing as regarded cost, three passengers could be carried with the former to one carried with the latter, and that must be an advantage. Again, in electrical traction the weight of the passengers was utilized for tractive purposes. Electricity worked automatically and the motor put its shoulder to the wheel. It did not require a movement of switches or resistance-coils, but as the work came so did the energy come to meet it; and the result was that electrical traction was economical because it was automatic. He did not wish it to be assumed for one moment that he did not see great difficulties in providing electrical traction on railways. The collection of the current had been alluded to by several speakers. Those who had watched electrical traction on the Central London Railway or on the trial line at Earl's Court, or even on tramways, would see a good deal of "fireworks." That did not mean much; it meant fusion of dirt and filings and things of that sort. But Sir Douglas Fox had mentioned that the Baltimore and Ohio Railway had experienced difficulty with their trolley-wire from high pressure. The trouble referred to had not been due to the high pressure: it had arisen in the Baltimore tunnel from the enormous current that had to be picked up, amounting at times to as much as 3,000 amperes; that current per square inch of copper meant electric welding, and something had to give way. The higher the pressure, the simpler it was to collect the current. For working a line like the Central London Railway, a pressure of 500 volts meant that a current of 1,000 amperes was needed for 750 HP.; but if the current were taken at 3,000 volts instead of 500 volts, the necessary current would at once be reduced to 160 amperes; and if the pressure were as high as 10,000 volts, which was being tried in Germany, the current needed was only 50 amperes. What was being done on the Central London Railway with 1,000 amperes could be done with 50 amperes at 10,000 volts, and if that pressure was used the whole problem was simplified. The use of such high voltage was considered to be dangerous, but the danger was not in the voltage, it was in the strength of the current. Not long ago a charming illustration of this fact had been given at the Royal Institution by Mr. Tesla, who had taken several hundred thousand volts through his body with impunity. He himself was constantly experimenting with Röntgen rays and induction-coils, and had unpleasant sparks 5 or 6 inches long tingling through him. In such cases the pressure was over 100,000 volts, but the shocks had not killed him yet. He would rather stand 50,000 volts than 500 volts. If a man's hand was moist and he took hold of a trolley-bar and touched a live wire, he would get through him

sufficient current to kill him; but if his skin was dry and he wore gloves, he might take several hundred volts and feel no effect whatever. There was no danger in electricity if proper precautions were taken. The fact that the higher the voltage, the easier it was to collect current, was one of the great merits of the multi-phase and single-phase systems which had been brought forward. The recent arbitration had brought out a great many useful facts, but engineers ought rather to look at the broader question, no matter whether continuous current, or single-phase or three-phase alternating current was proposed for the system of working. The Authors had made a splendid fight for the use of single-phase currents, and their summing up of the conditions best calculated to meet the requirements for a general system was very good, namely, "The selection is thus brought down by a process of elimination to a single-phase alternating-current system for the generation, transmission and distribution of the power, with one overhead conductor, and a return conductor on the ground, which can be either the rails or an insulated conductor, at practically the earth's potential." That was a very far-sighted observation. Mr. Webb, however, had asked for another Marconi to transmit the energy from the rails to the train without any wires at all. Experiments with that object were now being made in Belgium, where a Mr. Dutait had a tangential system whereby the train picked up the energy without any visible connection; and although the whole thing was in a very infantile stage, it had about it sufficient strength for him to prophesy that not many years would lapse before a Paper would be brought before the Institution to describe the system. Progress had been slow, not only in England but in every country, and slower in America than in England. Everybody imagined that the Americans were the active spirits who were developing the applications of electricity with an energy that was simply wonderful; but it should be remembered that England had started telegraphs, the block system, and automatic signals for railways, and had originated electric light and electrical traction. The first electric railway started had been that at Portrush in 1883, a light railway with a third rail at the side of the road. That had been followed in 1885 by the Bessbrook and Newry Railway. The City and South London Railway had been opened in 1890, and the Liverpool Overhead Railway in 1893. Electrical traction had been started in England before a single line had been opened in America. He had been in America in 1884, with Sir Frederick Bramwell, and had gone to Cleveland to see an experimental line put up there. In the previous year Sir William Preece.

Sir William Preece. he had been instrumental in introducing the tramway at Blackpool, and he had been able to say to his electrical friends in America, that if they wanted to know how to work a tramway they should come to England. He did not think the time had arrived for considering the application of electricity to main lines. It was necessary to go step by step. Electrical traction was wanted not so much on long lines as on the suburban lines. The members would remember the controversy before the Committees of the House of Commons on the question of carrying traffic between Liverpool and Manchester at the rate of 110 miles or 120 miles per hour. The Bill for the project had passed both Houses. While the speed of a steam-locomotive on the level was limited to 80 miles per hour, with electrical working the speed could be raised to 120 miles per hour. But that could not be done on the existing lines with the ordinary gauge. He did not say for one moment that the mono-rail system was the solution of the difficulty, but he did say that electrical traction had given railway managers the means of running trains at a speed far exceeding that of the fastest express train, even as high as 150 miles per hour. In addition to the prophecy he had made, that energy would be transmitted without wires, he might venture also to prophesy that the great centres of commerce would be connected by lines on which the population would travel at the rate of 120 miles or 125 miles per hour.

Sir Frederick Bramwell. Sir FREDERICK BRAMWELL, Bart., Past-President, gathered from Sir William Preece's remarks that he was endeavouring to establish that the speed of trains might be accelerated more quickly by electricity than was done, or could be done, by steam, and that this might be brought about without shock to the passengers. Sir William had alluded to the mono-rail inquiry before the Parliamentary Committee, where it had been generally agreed that the speed of a train could be reduced at the rate of 3 miles per hour per second, without shock to anybody. He had pointed out that no more shock was caused to a passenger when reducing speed from 100 miles per hour than from 20 miles per hour. The only thing was that the so-called shock—which was quite an improper name for it—was continued for a longer period. Whatever humanity could bear in the way of retardation, humanity could equally well bear in the way of acceleration at starting. Probably many of the members had read a recent petition of a number of gentlemen to a Government department, as to allowing a higher speed for motor-cars. The figures given therein appeared to show that a motor-car going at 24 miles per hour could be brought to a stand-

still in a distance equal to three times its length; and supposing that three times its length might fairly be taken as 40 feet or 42 feet, it would be found, if the statement were true—and, having regard to the names appended to the petition, there could hardly be any doubt about it—that instead of the speed being reduced by 3 miles per hour per second, it was reduced by 8 miles per hour per second, and the shock, even after allowing for the resilience of the pneumatic tires, would be practically as severe in the motor-car as in a railway carriage under the same conditions. Therefore he thought it was quite clear that the apprehensions of injury in getting up speed and in stopping had been quite unnecessary. The illustration he had given before the Committee, of an ordinary swing at a fair, showing that when a swing went only to 45° on each side of the vertical a speed of 10 miles per hour was alternately gained and lost in 1 second, was a proper illustration, and was corroborated by the foregoing facts relating to motor-cars. Therefore he thought any fear of difficulty arising from starting or stopping at a higher rate than was usual on steam railways might be dismissed as groundless. Sir Frederick Bramwell.

Mr. James Swinburne considered that the whole subject ought really to be divided into two branches. In towns there were short passenger lines, having many stopping-places and a very large number of passengers; while the main-line traffic was totally distinct, with difficulties and facilities of its own. The present practice really meant turning metropolitan railways into large tramways; it was simply the application of the practice of ordinary street tramways to railways. To some extent it was working well; but it had its limits; and some alteration would have to be made before much more was done. The pressure in use was 500 volts, but in order to transmit power over long distances, or to save in the cost of mains, that pressure would have to be increased, and he did not see why it should not be. There was no actual difficulty in making motors for much higher pressures; and if there were any difficulties, no one would be more capable of overcoming them than was Mr. Mordey. But there was a prevailing idea that it was necessary to use low pressure, even on long railways, which was absurd. The chief point for consideration in town railways was acceleration: and, as had been pointed out, the limit of acceleration was not a question of discomfort. He could not help suggesting that there was a total misapprehension about discomfort. The only effect of acceleration, so long as it was uniform, was that passengers standing up must lean forward at a small angle. An acceleration of 3 feet per second per second meant that a person Mr. Swinburne.

Mr. Swinburne. standing must lean about 3° or 4° from the vertical. In getting off an omnibus going at 8 miles per hour the acceleration was about 24 miles per hour in one second. The real difficulty in accelerating rapidly, however, was not the inconvenience to passengers. There was some inconvenience to passengers in starting the acceleration and in stopping it, the rate of acceleration being important. Passengers standing when the train started, would fall down unless they leaned over to begin with: those sitting down would feel nothing, except that they might imagine the train to be slanting a little. It was easy for a passenger to know when the train was about to stop and to adapt himself to it, and therefore there was no difficulty in stopping. The great difficulty was that, if very rapid acceleration was required, power must be poured into the train at starting. Taking the urban train with large acceleration, such as 3 feet or 1 metre per second per second, or even a little more, it would be found to require thousands of kilowatts, which meant very large motors and considerable demand on the central station. Acceleration controlled the mean speed, because on short lines trains were practically always starting or stopping, and the time run at full speed was unimportant; therefore acceleration was of vital importance. One method of getting high acceleration without too much drain on the power-station was to make the trains lighter, a matter rather of railway engineering than of electrical work. Lightness had not been important hitherto, but as soon as the acceleration became high, lightness of carriages was of great importance. The existing system was complicated and in many ways uneconomical in distribution, and very wasteful in resistances. In working at constant potential, a third of the energy was wasted, even if the motors had no resistance at all: in ordinary work a great deal more was wasted, even when a train was worked properly; and when it was worked by the average train-boy still more was wasted. The great problem in urban railways was to train the drivers and so arrange the system that there was not too much waste in resistance. The Authors had proposed alternating currents, which had a great advantage in respect of ease of distribution. There was not the same difficulty in distributing in short lines. The real difficulty was to get an alternating motor that would accelerate well. An alternating motor used on an urban line was never running at full speed; it was always starting when it was doing anything at all, and the rest of the time it was stopping. The method which he believed would have to be adopted was a method proposed many years ago, and he thought forgotten. The

armature and field were always running at full speed relatively; the armature drove the train, and the field-magnets were allowed to run loose, so that, when a train stopped, the field-magnets were going at full speed, and when the train was started a brake was put on the field-magnets and energy was wasted. The energy wasted was equal to the kinetic energy of the train at full speed, and that was very considerable when wasted every time of stopping. But it was quite a possible engineering matter, as it only meant a water-cooled brake which would evaporate 3 or 4 gallons of water every time the train started. There was no difficulty in putting on a mechanical brake, which would make the alternating system possible, but it precluded the possibility of returning power in slowing down. On urban railways, nearly the whole of the energy was transformed into kinetic energy; the tractive resistance was comparatively a small item. In the use of high acceleration, such as would be necessary in the future, a system was required that would return some of that kinetic energy. Lord Kelvin considered that enough attention had not been paid to series or constant-current systems. He had lately been going into that question fully, and would point out that the series system practically met every requirement of urban railways. At the start there was only a loss in the motor and no loss in resistances, and therefore a saving was at once effected of 30 to 50 per cent. The train could run easily through the middle portion of the section, and when slowing down it returned as much energy as the efficiency of the motor allowed. The efficiency of a series system where the trains were continually starting or slowing down was beyond that of any of the systems at present in use, and far ahead of the ordinary continuous-current constant-pressure system. The Ward Leonard system was an electrical variable-speed coupling, and would do almost anything. Its efficiency was rather low, and he was afraid it would be too expensive. Locomotives had been made for so many years that they were fairly cheap; but if high acceleration was to be secured and it was remembered that a motor was needed capable of taking between 1,000 HP. and 2,000 HP., which was to be transformed by another motor and another generator, he was afraid the expense would be prohibitive. He could not help thinking that electrical engineers had not yet gone far enough to say that they could do anything in connection with long lines. But it was not the less important that the subject should be considered. The "tubes" stood alone; their gauge was different

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Mr. Swinburne. from that of other railways, with which they were not connected. The suburban traffic would be the next to come under the influence of electricity, and, in considering that traffic, systems ought not to be adopted which would not be available eventually for long lines. It was desirable to consider the main-line problem in advance and not to leave it simply to chance, with the result that eventually a system had to be adopted which was not suitable for long lines. The difficulties with regard to main lines, he thought, were four. In the first place, there was the difficulty of distribution. Secondly, acceleration was of no importance: the series system, which was exceedingly useful for short lines, lost most of its advantage on long lines, because the system of acceleration and returning energy did not apply; the waste of kinetic energy being so unimportant that it had not to be considered. The third difficulty arose from the fact that the traffic was absolutely different. With a short "tube" line in London, the more trains put on, the more passengers were carried. The traffic practically made itself, the passengers coming as often as there were trains. But on main lines it would be quite otherwise. For instance, it would be no good running a 5-minute service of express trains between London and Glasgow, as no more passengers would be obtained to occupy them. Such a line was not taking away passengers from steamers and omnibuses, and therefore the number of passengers would remain almost constant; but perhaps, if the fares and rates were lowered, the passenger traffic might be increased slightly, and the goods traffic considerably. The fourth difficulty was the goods traffic. To render an electrical system useful for long main lines, the whole problem had to be considered from beginning to end. It could only be thought of at present in a very sketchy way. On long lines the alternating-current system had the advantage of easy distribution. In this respect no other system came anywhere near it. The loss in starting was unimportant; but there was considerable difficulty in that the trains would run at only one speed: any other speed meant considerable waste of power. He did not know whether in practice it was possible to arrange trains to run always at one speed; or, if not, to coast a little, then to lose power by friction-brakes, and to gain speed again. He did not mean that every train would run at the same speed as every other train; that would depend on the motors: what he meant was that each train would run at the same speed always. The series system again would be applicable to long lines. It would involve bare overheard conductors with high pressures and very high pressures between the motors and their frames, but not high

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pressures in the commutators. If it was worked out with dangerous high pressures on bare conductors overhead, the series system would permit of transmission over long distances with high efficiency, because there were no transformers. Another curious result was that the engines and dynamos at the station always ran with full load, but at varying speeds. When there were no trains they were simply crawling round under full steam, and when there was a heavy load the engines were simply run faster with the same cut-off. With regard to short-distance traffic, the electric railway was actually in advance of the demand, the real difficulty being to get the order to make the plant. For long lines he did not think the problem was nearly solved, and it would present many difficulties. For instance, the multiple-unit system could not be used for shunting, as motors could not be put under all the trucks, some of them not belonging to the railway company. With regard to signalling, it should be remembered that the introduction of electrical traction on long lines would get over a great deal of the signalling difficulty, because it would give complete control of the lines from the shore, so to speak. Trains could run during fogs, and all the engine-driver would have to do would be to look out and see there was nothing on the line: he would have nothing to do with danger-signals, because his running would all be settled for him at the station. Nevertheless, he thought it must be admitted that electrical traction was better adapted at present to short lines of urban and suburban traffic; and with a little ingenuity the existing systems could be greatly improved: but it was not possible to take in hand long main lines at all, and it did not look as if it would pay at present. The only thing to do was to take note of what was going on, to look ahead, and to see that a system was not adopted on suburban lines which would be unsuitable for long lines.

Sir John Wolfe Barry.

Sir JOHN WOLFE BARRY, K.C.B., Past-President, remarked that, as Sir William Preece had alluded to some experiments made on the Metropolitan and Metropolitan District Railways within the last 2 or 3 years, it might be of interest if he gave a few particulars of them, and expressed the opinion he had arrived at upon the general question of electrical traction. He had come to the conclusion, 4 or 5 years ago, that for urban and suburban traffic electrical traction was the system of the near future, but he had found difficulty in persuading some of his clients that such was a true view of the subject. About 1899 he had induced the two Metropolitan Companies to allow him to make a temporary installation of electric plant, and to work one of their ordinary trains

Sir John Wolfe Barry. backward and forward between Earl's Court station and High Street Kensington station. That part of the line had been selected because it happened to have particularly steep gradients of 1 in 43, 1 in 62, and 1 in 70, and also very sharp curves. He had been anxious that the two companies should see one of their ordinary trains actually working under electrical conditions. At that time the Central London Railway had not been opened, and the heaviest electric trains in the country had been the small ones running on the City and South London line. The trains on the Metropolitan and Metropolitan District Railways weighed 180 tons empty, and about 230 tons loaded. One object in view had been to gain experience in the electrical working of such traffic, and to see how it could best be introduced without interfering with the use of the line by the steam-locomotive; because it would be generally admitted that whenever electrical traction was introduced on to such busy lines previously worked by steam-locomotives, the process would have to be gradual: there would not be a time when every steam-locomotive could be taken off and all the electric locomotives could be set to work. Another object had been that the staffs of the two companies might pass through the training which would be afforded by the experimental train, and so learn their future duties. He certainly had had every hope that electrical traction would have been introduced forthwith on the Metropolitan and District lines; but unfortunately some differences of opinion had arisen between the controlling powers, and the thing had not come about as soon as he had expected. However, he thought it might be anticipated that possibly not much more than a year would elapse before electrical traction was introduced on those lines, although it might have been done 3 years ago if everybody had made the most of their opportunities. The train prepared for experiment had had at each end a motor-carriage weighing, when loaded, 54 tons, one motor always running idle as there had been no multiple control. The reason for this arrangement was that the train had been a shuttle train, running backward and forward between the two stations. Under the special circumstances, there had been no possibility of turning it or of the motor-coach changing ends, and he supposed it would have been against all Board-of-Trade rules to propel the train from the rear. Under the advice of Messrs. Siemens the same electrical system had been adopted as on the Central London Railway, namely, low-level conductors with 500-volt continuous current. In the case under consideration there had been a conductor on each side of the running-rails, because for various reasons, which he

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need not go into, it had been considered undesirable to have the return current by a bonded rail. On a heavily worked line a bonded rail—which had to be connected with copper rivets—was certainly not convenient for rapid replacement in the event of repairs. In an experiment to which he was about to refer on a gradient of 1 in 43, the motor had developed an initial tractive force of 9½ tons, and a maximum tractive force of 16 tons when running at 2½ miles per hour, corresponding to a draw-bar tractive force of 12¾ tons. Of course in ordinary running the tractive force required was much less. He understood Mr. Webb had stated that one of the best of the London and North Western Railway locomotives, when working a train of 420 tons at 50 miles per hour, had developed a draw-bar effort of 5¼ tons, and when starting of about 6 tons. The motor which on the experimental line had developed 9½ tons had afforded a valuable illustration of the tractive force which could be developed by electrical means when required; for he had purposely stopped a heavily loaded train on the incline of 1 in 43, and after the most powerful engine of the Metropolitan District Railway had proved quite unable to move the train, current had been supplied to the motors, and the electric locomotive had taken up the gradient of 1 in 43 not only the train but also the steam-locomotive, without the least difficulty. In another experiment a steam-locomotive had been attached to the electric train, and both had been started at the same moment in opposite directions. The electric locomotive had immediately and easily overpowered the steam-locomotive, and the result had been the same when on another trial the steam-locomotive had been permitted to start first and to get the train into motion. Several speakers had already alluded to the value of electrical traction in the matter of acceleration, and it had been found in these experiments that there was a large gain in acceleration over any of the steam-locomotives on that particular portion of the line. With electrical traction it was possible to obtain, running backward and forward, and starting and stopping within 2 minutes or 2¼ minutes, a mean speed of 22 miles to 23 miles per hour, which was largely in excess of the average speed on the Metropolitan lines generally. All the foregoing figures appeared in the report which had been presented to the two companies, and which on some future occasion might perhaps find its way into the Library of the Institution, if the two companies gave permission. It contained valuable particulars concerning matters which were looked at more from the point of view of the practical working of the railway

Sir John Wolfe Barry. than from the point of view of an electrician; because, while he did not set up to be an electrician, he had given some attention to the general problems connected with the working of railways and with engineering matters generally. There were certain difficulties which would be met with in working railways electrically, and which would have to be surmounted; for instance, the difficulty presented by junctions, long cross-over roads, and station-yards, when the whole train was not actuated by electricity. If a locomotive was employed, and it was brought to rest upon a gap in the cross-over roads or junctions, it became powerless; and some means must be found for getting over that difficulty. It was a difficulty which obtained more or less with low-level conductors, but he did not say that it could not be overcome. However, the more he considered the matter the more it seemed to him that the proper mode of dealing with the urban and suburban traffic was to actuate the whole train, and in that way avoid many of the serious difficulties of working with an electric locomotive. The question of overhead *versus* low-level conductors was one of much interest. It would be a very good thing indeed to get rid of all low-level conductors and run with overhead conductors; but he saw many practical difficulties in overhead conductors carrying the large amount of current which would be necessitated by restricting the voltage to anything like 500 volts. The conductors would be bulky, and they would have to be supported in some way; they would be out of the way of inspection; and, altogether, difficulties of that kind, to say nothing of the wear and tear of the trolley, might give rise to accidents to which low-level conductors would not be liable. The chief objection to the latter appeared to be the risk entailed to people on the level of the railway; but he did not see that that was a serious matter, as everybody nowadays was aware of the risk and took precautions accordingly. Electrical traction, then, seemed eminently suitable for urban and suburban lines; he did not mean merely in regard to questions of ventilation, but from the point of view that it enabled the number of trains to be multiplied and the line to be utilised to its utmost working-capacity. When it was considered that such railways sometimes cost £500,000 to £700,000 per mile, the object to be aimed at must be to get the maximum earnings out of lines constructed at such vast expense. It was obvious that, in respect of facility of acceleration, electrical traction carried the day. Any scheme for working long lines electrically was, as Mr. Swinburne had remarked, at present very sketchy: but he demurred to the suggestion to refrain from or to hesitate in

adopting the system which was best adapted to urban and suburban lines, because it might some day be found to be not the best for working lines between, say, London and Scotland. In such a matter, the future could take care of itself. Further, there seemed to be no particular reason, in the nature of things, why a system which was convenient for working long lines should necessarily be the best for suburban traffic. The conditions were utterly different, and the system of working could be as easily altered at some convenient place as it was now, where the tank locomotive finished its journey, and gave place to the long-distance locomotive. One of the questions which had been set at rest by the experiments made between Earl's Court and High Street, Kensington, was the question of vibration. It had soon been discovered that householders who had not complained and had never felt inconvenience from the working of the steam-locomotive, complained greatly of the working of the electric trains. At first the trouble had been considered to be imaginary, but there was no doubt it was not so, because careful measurements had been made and the amplitude of the vibration had been found to be undoubtedly much larger with the electric locomotive. The cause had been looked for and quickly traced to the fact that, owing to the form of electric motor adopted, the weight not carried on springs in the electric locomotive was nearly double what it was in the steam-locomotive. That difficulty had cost a great deal of money to remedy on the Central London Railway, but he was happy to say that its cause and remedy had been found out in 1900 by the experiments on the older underground railways. In conclusion, he would say to electricians, "Design a practical system for working urban and suburban lines; do not go too far towards the utmost that can be done by electrical science, but design a system which will do the every-day work of metropolitan and suburban traffic." He felt quite sure that it could be done, and within a very few years; and that ultimately all urban and suburban trains would be worked electrically, to the great comfort of the passengers and to the better prospects of the shareholders. Sir John Wolfe Barry.

Mr. W. GEIPEL considered that the primary object which the Authors had in bringing the Paper forward was to discuss which electric system was best suited for the working of railways, rather than to discuss the question whether electricity or steam was better suited for long railways or suburban railways; and it was from the former point of view that he wished to make one or two remarks. The systems referred to in the Paper should be reduced to three. Mr. Geipel.

Mr. Geipel. First, the three-phase cascade system; secondly, the composite system, with fixed motor-generators and low-tension conductors carrying the current from the stationary motor-generator to the locomotive; and thirdly, a single-phase alternating-current transmission with the motor-generator on the locomotive. It was the latter system which the Authors recommended, and he agreed with them. With the cascade system there were, in the first place, two overhead conductors, and, secondly, two motors, one of which was in use for only a small part of the time. To the disadvantages of the composite system for long lines mentioned by the Authors he would add that the cost of the low-tension conductors formed a serious obstacle to the introduction of that system for the working of large railways. With regard to the Ward Leonard system, Colonel Crompton had remarked that there were many mechanical difficulties to be overcome before it could be applied successfully, and considered the system in use at Burgdorf-Thun to be simple compared with that of *Fig. 9.* He did not wish to detract for one moment from the good work done by Messrs. Brown, Boveri & Co., but Colonel Crompton had not mentioned that on the Burgdorf-Thun line there were two overhead wires; nor that, in order to vary the speed from 40 miles to 20 miles per hour, it was necessary to change the gear on the locomotive and to stop the locomotive for the purpose. In the system shown by *Fig. 9* there was one trolley-wire carrying a small current, the collection of which, as Sir William Preece had pointed out, was a very different thing from collecting a large current. There was a motor-generator transforming the current where it was required into energy at the potential best suited for the particular speed at which the train was running at the time. At starting, the whole of the energy could be converted into low-voltage current, and there was no loss in needless resistances, while there was attained an acceleration which was incomparably superior to the acceleration attained by switching eight or four or even two motors from series to parallel or from parallel to series, as was the custom in the series-parallel control. The diagram (*Fig. 10*) exhibited by Mr. Cottrell showed large variations in the acceleration, and the whole point was that the rate of change of acceleration must be gradual in order not to be objectionable to the passengers. With regard to the weight of the locomotive on the Ward Leonard system, he thought there must be some error in Mr. Siemens's estimate that for 260 kilowatts with a 72-ton train the motor-generator would weigh 55 tons. He had in his possession a specification and a tender for

a motor-generator of 200 kilowatts which weighed only 17 tons, or, reducing it to the same size as Mr. Siemens's, 24 tons. From that increase of weight some deduction had to be made, because heavy series resistances were not required, nor the heavy switches for working them. And further, he was not at all sure that the increased weight might not frequently be found of great advantage. Often the locomotive was inclined to skid if too light, and that additional weight might then be useful. Mr. Swinburne had referred to the cost of the system as being prohibitive; but taking the figures given by the Authors for a motor-generator system, which was the Ward Leonard system at present most recommended for working railways, the Authors put the cost of the motor-generator sub-station at £15·2 per kilowatt, and that did not include the low-tension conductors, which in the Metropolitan District scheme had been estimated to cost £6 to £7 per kilowatt. The Metropolitan District Railway was one where the low-tension conductors would probably cost as little per kilowatt as on any line, and therefore he thought he was erring on the safe side in taking the cost at £7 per kilowatt; which brought the total cost to £22·2 per kilowatt. In the Ward Leonard system a step-down transformer sub-station was required, the cost of which for the alternating-motor system the Authors estimated at £3·7 per kilowatt. With the Ward Leonard system there were no peaks and no waste energy, and the electrical energy could be generated at the highest efficiency; consequently it was possible to reduce the cost of the sub-station considerably below £3·7 per kilowatt. The cost of the transformer sub-station he took therefore at £2 per kilowatt; the motor-generator on the locomotive could be had for £5 per kilowatt; and he estimated that the overhead conductor would cost not more than £0·5, making £7·5 per kilowatt in all, and showing a saving of £14·7 between the two systems. The switch-gear and the regulation was much simpler, and therefore he thought it would be safe to put the saving at £15 per kilowatt. Taking even so low a figure as 400 kilowatts per locomotive, there should be a saving of capital outlay, in the long run, by adopting the Ward Leonard system to begin with, of £15,000,000 on the 3,000 locomotives of the London and North Western Railway alone. That might or might not be the case in practice, but it was worth serious consideration at the present time, and for that reason he thought the Authors had done well to bring forward so important a question. With regard to the cost of working, the Authors pointed out that while it was necessary to have an attendant at sub-stations where motor-generators were in

Mr. Geipel.

Mr. Geipel. use, it was not necessary to have men where static transformers were in use, so that on the Ward Leonard system those men could be dispensed with. For the motor-generators on the locomotives, no additional labour was needed, as the Board of Trade already required that there should be two men on the locomotive, and either of those men was quite able to give the small amount of attention needed in keeping the motor-generator running; in fact it was merely necessary to start it at the beginning of the journey; nothing else was required if the bearings were automatically lubricated. As to the loss of power in the motor-generators, this—in the case of fixed motor-generators—took place all along the line, whereas with motor-generators carried on the locomotive the loss occurred only where the locomotive was working. Further, with the fixed motor-generator it was necessary to make provision for dealing with congestion of traffic at all points of the line; whereas in the case of the motor-generator carried on the locomotive that difficulty did not apply, the loss being proportional to the number of locomotives in use. He was aware that the objection did not apply with equal force to suburban lines where the distribution and number of the trains was fairly regular; but for inter-urban lines it was a point of considerable importance, and it was in this respect that the steam-locomotive (which was so self-contained) had an advantage which the Ward Leonard system more nearly emulated than the fixed motor-generator system. Again, the loss in resistance in regulating the motors was much smaller with the Ward Leonard system, inasmuch as the energy was delivered to the motors at a voltage exactly suited to the speed at which the motors were rotating; and in effecting this the only loss of energy was the small amount lost in the resistance for varying the magnetism of the field-circuit of the generator; there was in fact no resistance in the main circuit. With the series-parallel control the resistance was in the main circuit, and it was always necessary to use the energy at the full voltage of the supply. An object-lesson of the wastefulness of this system was afforded by the remarks of some previous speakers as to the difficulty of using electric locomotives for shunting. The only difficulty appeared to lie in the fact that when using the locomotives at low speed it was necessary to provide for such a heavy loss of power in the controlling resistances; so that in shunting there should be a large economy of energy by the use of the Ward Leonard system. On the score of wear and tear there was also less expense involved in that system, and this was a serious item in the case of parallel control where

large powers were involved. At p. 74 the Authors referred to possible difficulty with the commutators, but he could say from personal knowledge that there was no such difficulty with the motor-generators, if they were properly designed. This fact had been borne out by the motor-generators used for starting the platform at the recent Paris Exhibition, which had required 1,200 kilowatts; and in London there was working at Messrs. Lloyd's printing-works a 50-kilowatt plant, where also there was no difficulty; while the beauty of the control in passing from no speed up to full speed was unique. The points which he thought formed good reasons for supporting the system recommended by the Authors might be summed up as—(1) rapid acceleration and retardation without affecting the comfort of passengers; (2) use of only one high-potential overhead wire carrying small current; (3) low cost of transforming-plant; (4) low cost of the power-plant; (5) low cost of working; (6) energy supplied to the motors always at the voltage suited to their speed; (7) saving of wear and tear generally. On the question of periodicity he desired to join issue with the Authors' statement that, in consideration of the lighting, a lower frequency than 40 periods per second would probably not be used. This question was one of vital importance if the alternating system of transmission was to be adopted. If a multitude of frequencies (such as were unfortunately to be found in central electric-lighting stations, and had caused so many difficulties and troubles) were adopted on railways, it would be a very serious matter to the railways as well as to the electrical industry. It was desirable, therefore, that an agreement on this point should be come to at the outset, and he was sorry to see that the Authors had introduced into the consideration the lighting of the trains, for which reason they recommended 40 periods per second. He would suggest that the power required for the lighting of the trains was so small that it might be neglected. For lighting an average train 3 or 4 kilowatts sufficed, and this was in use only during the hours of darkness and in tunnels; so that the energy used was probably a fraction of 1 per cent. of that used for traction. It had been pointed out by a previous speaker that the periodicity best suited for motors was lower than 40 periods per second, and he would add that the loss in the conductors was less at the lower periodicity. He ventured to suggest that a frequency of 25 periods per second, recommended some time ago by the Institution of Electrical Engineers as very suitable for power purposes, was more applicable to operating railways than was the frequency of 40 periods suggested by the Authors. The lighting of the trains Mr. Geipel.

Mr. Geipel. might be effected in various ways. He would further suggest the importance of adopting some standard voltage both for the high tension and the extra-high tension. For the low tension there was already 500 volts, and he noticed that in one scheme 11,000 volts for the high tension was recommended. It appeared to him that either 10,000, 15,000, or 20,000 volts might be adopted with greater advantage. He had referred to these two questions on account of the paramount importance to the railway companies of having plant which would be interchangeable between the various railway systems in the country; and with this object in view it appeared to him that the time had come when a joint Committee might be appointed by the various engineering societies to make a recommendation on the subject.

Mr. McMahon. Mr. P. V. McMahon remarked that the discussion had turned so much on the electrical equipment of main lines that any reference to so small a line as the City and South London Railway would seem almost out of place. As, however, the Authors referred to the three-wire system in operation there, a few further details of that system might be of interest. The two-wire system used on the City and South London Railway from the beginning had worked very well for 9 years, but when need had arisen for a quicker service of heavier trains, it had been available no longer. All possible systems having been considered, the conclusion had been come to that the three-wire system would meet the case; and it was interesting to know that after 2 years' working the Company had every reason to be satisfied with the system and the contractors. One or two novel points had had to be settled before installing the system. In the first place there had been the problem of getting from the negative to the positive side, and several automatic devices had been considered; but the solution of the difficulty had finally resolved itself into a simple break of 30 feet in the working-conductor at the crossings. That had given rather a flickering light in the train, but the break had been reduced afterwards to 15 feet by putting conductors in the middle and a fuse between; so that, if by any chance two locomotives were crossing and caused a short circuit, the middle piece would become disconnected from the main conductor. Another question decided had been whether two machines should be used at 500 volts, one on each side of the system, as shown in *Fig. 2*, or 1,000-volt machines across the outers, with smaller machines for balancing. Many things had pointed to the use of generators working at 1,000 volts; but one point that had seemed to be very

important was that a bad short-circuit, such as might be caused by a car running off the line and directly connecting the third rail to the ordinary running-rail, might raise the pressure to 1,000 volts between the running-rail and the working-conductor. The circuit-breaker would probably act, but in the meantime the pressure might be raised on the motor and lamps, and a number of the lamps would be blown out by the temporary rise in the voltage. The Authors referred to the efficiency of sub-stations on the three-phase system, as on the Central London Railway. From *Fig. 4* it would appear that with a transformer and rotary converter the efficiency at quarter-load was 83 per cent., while the continuous-current reducers which were in use on the City and South London Railway in the sub-stations had an efficiency of 90 per cent. at quarter-load. The rotary convertor and transformer had an efficiency of 90 per cent. at half-load, 93 per cent. at full load, and 92 per cent. at 50 per cent. over-load; while the continuous-current machines had an efficiency of 94 per cent. at half-load, 96 per cent at full load, and about 96 per cent. at 50 per cent. over-load. In Appendix I., in connection with the energy given out from the generating-station and from the sub-stations, an overall efficiency of 93 per cent. for the Central London Railway was mentioned, but it seemed that the loss in the cables must have been omitted. On the South London line at the sub-stations, especially the sub-station at the Angel, where the high-tension reducer system with reversible boosters in connection with a large battery was in use, a very high efficiency was obtained, because the high-tension feeders, supplying sub-stations at 1,000 volts, had an absolutely steady load throughout the day of between 75 and 80 amperes, while the current going from the sub-station bus-bars to the line varied between zero and 450 amperes, as shown by recording ammeter charts at the generating-station and sub-station. If a system of that kind were applied all over the line, the size of the units in the generating-station, and the size of the feeders, could be reduced for the same number of trains. At London Bridge sub-station there was a battery almost as large, but it had failed to take the peaks with the ordinary boosters, and was not much good as a regulator; in fact, it would do very little work at all unless additional cells were switched in and the battery was allowed to discharge on the whole. It was used in case of a heavy load, and the cells had to be switched in to make a discharge. With regard to special cables for the lifts and lighting, that was an important item. On the City and South Mr. McMahon.

Mr. McMahon. London Railway there was an arrangement whereby the lift- and lighting-circuits were fed from the same bus-bars, but in the case of a heavy short-circuit on the working-conductor an automatic cut-out operated and threw the lifts and lights on to the battery, thus maintaining the station-lighting and lift-supply in case of the working-conductor blowing its fuses. He had expected to hear more of the relative merits of the alternating- as against the continuous-current system. Comparing the continuous-current three-wire system used on the City and South London Railway with the three-phase system, it would be seen at once that a good deal less needed to be spent in copper, on account of the steady load on the feeders. There was very little difference in the rail-drop between 5¼ miles and about 3 miles, and it would seem that the limits for the three-wire system had not by any means been reached. Previous to the installation of the system it had been thought there might be some difficulty in the balancing, but none had occurred. Ordinary balancers were installed at Clapham Common, Moorgate Street, and the Elephant and Castle, and it was found that the continuous-current reducers acted so well as balancers that only one of the balancers needed to be used. The ammeters in the reducer-motor armature-circuit at the sub-station showed that the current was fairly steady, while the generating armature currents were varying between zero and the maximum, showing that they were acting as balancers as well as reducers. The question of loss in the series-parallel controller was much overrated in the Paper, and he failed to see how two-thirds of the energy could be wasted at starting. The question had been gone into carefully when the design of some new locomotives for the City and South London line had been under consideration. Experience showed that, of the total energy used in a short section of 2,700 feet to 3,000 feet, about 50 per cent. was used in getting the train up to full speed from the start. The loss in resistances, provided the motor had a high tractive force per ampere, was about 10 per cent. to 15 per cent. during the starting-period, or 5 per cent. to 7½ per cent. over the whole line. A great deal depended on the driver. If he did not cut out his resistances and maintain the current at the maximum allowable value, a great deal could be wasted; but if he watched the ammeter and kept the current steady until he had lost control over it, due to the back electromotive force of the motor, the maximum loss was about 5 to 6 per cent. On a longer section the loss was much less. He thought the figure given by the Authors for the units per ton-mile on the Central London

Railway must include the lighting- and lift-currents,[1] because Mr. McMahon. on the City and South London line at the switchboard it was 0·0689 Board-of-Trade unit per ton-mile at an average speed of about 17 miles per hour, including starting and stopping, but not time at stations. While on that question, it might be interesting to give some of the results obtained on the City and South London line in the past half-year's working. The coal consumed per ton-mile at the switchboard for the half-year was 0·3125 lb., including lighting boilers and all losses in connection with the generating-station. On the locomotive, however, it would be much lower, because the above figure included the shunting and sub-station and cable losses; but the energy per ton-mile on the locomotive was 0·0552 Board-of-Trade unit, which in coal was equivalent to a little more than was obtained on main lines. The quantity of energy used in starting on short electric lines, made the consumption of energy, and consequently the coal per ton-mile, very high when compared with steam-locomotion on main lines. An electric locomotive on a long journey with only one start would probably show lower coal-consumption than the existing main-line steam-locomotive. The actual coal-consumption was a little under 3 ounces per ton-mile, where the tractive resistance in the tunnel, as shown by a number of experiments, was at least double that on main lines. The Authors put forward in Appendix II. the ratio of the working-expenses as a sort of indication of the relative merit of the two systems therein referred to, but they did not take the results shown in the respective balance-sheets. They added a little on account of the higher fare per passenger on the City and South London line, and he thought that was hardly right, because the Central London Railway had a better mid-day traffic than the South London. The respective percentages of working-expenses on receipts should be 46·74 per cent. and 53·78 per cent. In the Table at p. 45 there were also two items which were not quite comparable. A previous speaker had referred to those items and had mentioned law-charges, a matter he did not propose to deal with; but on the Central London Railway the repairs to the lifts were included in "repairs of carriages," while the City and South London Railway charged such repairs to traffic-expenses. If the figures were altered to the South London system, carriage-repairs on the Central London line were 0·027*d.*; on the South London, 0·036*d.* per passenger. The traffic-expenses should be 0·429*d.* for the Central London and

[1] See the footnotes to pp. 81 and 153.—SEC. INST. C.E.

Mr. McMahon. 0·428*d.* for the other line. He thought the figures given by the Authors in Appendix I. did not allow of a comparison being made, as the coal used in the 3 months for which the units were given was not stated. Taking the net results of the Table, it seemed that the cost per passenger, even as put by the Authors, was 8·3 per cent. higher on the Central London Railway than on the City and South London Railway. Whether the system had anything to do with that it was difficult to say. The cost of coal per passenger, according to the half-yearly balance-sheets of the Central London Railway, worked out at 0·1575*d.*, while on the South London line it was 0·0982*d.*, showing that on the former coal per passenger cost 60 per cent. more than on the latter. Apart from the question of system, there was the question of rapid acceleration. That also had been gone into very carefully when re-equipping the City and South London line, and it had been a question how far the Company could go without paying too much for acceleration. It had been found that with the locomotives under consideration, and with locomotives and trains weighing about 49 tons, including passengers, the time taken on a short section of 2,700 feet would be 130 seconds, the maximum speed being 19·7 miles per hour, and the energy per ton-mile on the locomotive 0·054 Board-of-Trade unit with an average speed of 14·25 miles per hour. It had been thought a much better service might be obtained by having a four-motor equipment, the total weight remaining at 49 tons, but with a reduction in seating-capacity. The energy consumed per ton-mile had thus been reduced to 0·0377 Board-of-Trade unit, the maximum speed being 20·6 miles, and the average speed 14·25 miles per hour as before. The reduced energy per ton-mile had been obtained by increasing the acceleration, but the peaks at starting had been increased from 300 amperes to 600 amperes. That had an important bearing on the size of a generating-station, on the amount of copper in feeders, and on the size of the working-conductor. The foregoing results assumed that the current could be shut off as soon as full speed was attained and the locomotive be allowed to coast; but that would hardly be the case in practice. Running the above-mentioned locomotives at their maximum speed, and keeping the current on until the brakes were applied, the times for a 2,700-foot section were 122 seconds and 103 seconds, while the energy per ton-mile was 0·0659 unit and 0·745 unit respectively. Considering this effect on the power-station of a line with ten such sections, allowing 10 seconds at each station and running a 2-minute service, so that thirty trains left the terminus per

hour, the maximum current demand would be 2,085 amperes, and with four motors 4,300 amperes. The time for the journey with the two-motor equipment was 21·8 minutes, and with the four-motor equipment 18·67 minutes. The difference was an increase of 13·5 per cent. in the units per ton-mile with the higher acceleration, and the power-house would have to be enlarged by 63 per cent., while only 14·3 per cent. would be saved in time. Unless the competition with trams and other means of locomotion was very severe, such extra expenditure in order to obtain high acceleration was not warranted. Another thing was that the energy would not be generated so economically with a very variable load. It would almost appear that when a high acceleration was required some such system as the Ward Leonard system, where there were not very high peaks, would meet the case, although that system had not been tried. Examination of the recorder charts of the City and South London Railway showed that with well-governed engines the voltage in a traction-station could be kept as steady as in a lighting-station. The effect of the high-tension continuous-current system was also shown to be good as far as the sub-station and line-voltage was concerned. A large battery working with a reversible booster was seen to give a steady load on the feeders, although the live current varied considerably, and the three-wire system kept the rail-drop within low limits, on account of the rail-current being on the whole only local. Mr. McMahon.

Mr. A. Dobree observed that as reference had been made in the Paper and in the course of the discussion to the experiments conducted near Berlin on the high-speed railway, some further particulars of that line might possibly be of interest for the purpose of comparison. The experiments had been made not only with a view to determine what could be done in the matter of high speed, but also in order to see how far the system could be applied to existing or new long-distance railways. The cars had been designed with a view to meet those conditions. The first experiments had been conducted by Messrs. Siemens and Halske, in 1898, when they had used a pressure of 10,000 volts, and the current had been collected directly, and passed to step-down transformers on the locomotive. The construction of the overhead line, the method of collection, and the general arrangement of the scheme had proved so successful that it had been adopted, with slight modifications, for a new line which had been running towards the end of 1901. The two cars had been supplied to the order of a syndicate formed for the purpose of carrying out Mr. Dobree.

Mr. Dobree. these particular experiments; one car by Messrs. Siemens and Halske and the other by the Allgemeine Elektricitäts Gesellschaft. A track to the south of Berlin had been placed at their disposal by the military authorities. The line was nearly straight, the sharpest curve having a radius of over 1,000 yards, and the steepest gradient was 1 in 185; so that the conditions were very favourable to the experiments. The length of the line was exactly 11¼ miles; the total weight of the car was 94½ tons, including passengers, and that weight was made up of the body, frame, truck, wheels, and axles, 48 tons; motors, resistances, and controlling-gear, 27 tons; step-down transformers, 12·3 tons; and sundries and passengers accounted for the balance. In comparing those weights with the figures given by Mr. Siemens, it should be remembered that in the case of the German car the whole of the apparatus was specially and carefully designed for a specific object; but in the weights given by Mr. Siemens, standard machines had been taken simply for the purpose of a rough estimate, which no doubt could be greatly reduced if the whole thing were carefully designed. Also, the maximum speed contemplated by Mr. Siemens was 60 miles per hour, whereas in the case mentioned the normal running speed was 125 miles per hour, and 137 miles per hour was contemplated. A speed of 100 miles per hour had been actually reached in the autumn of 1901. The calculated draw-bar pull at full speed of 125 miles per hour was 3,000 lbs., and of that amount 2,000 lbs. was calculated as being required to overcome the air-resistance, the balance of 1,000 lbs. being required for the tractive resistance. Measurements had been made on the car when running which gave the following approximate results. At 87½ miles per hour the total pull was 1,800 lbs. made up of 820 lbs. for air-resistance and 980 lbs. for tractive resistance; at 81 miles per hour the pull was 1,670 lbs., made up of 700 lbs. for air-resistance and 970 lbs. for tractive resistance. Before putting the cars in hand, Messrs. Siemens and Halske had conducted some elaborate experiments to determine the air-resistance,[1] and the results they had obtained had been borne out very closely in actual practice. The air-resistance on the car was measured by means of a U water-tube, and connections were laid from that tube to various points of the car, to the roof and the front, and to different distances from the front, so as to avoid any error with regard to what might be called the "air-buffer" effect. When the cars had been at work for some little time, a series of

[1] See Minutes of Proceedings Inst. C.E., vol. cxlvii. p. 203.

Mr. Dobree. ten journeys had been made continuously with a view to reproduce as nearly as possible the conditions of a run of 150 miles with three stops. At the conclusion of that run the temperature of the motors and of the transformers had been taken, and the rise of temperature had been found to be 81° F. in the motors, and 54° F. in the transformers; showing that the car as designed was thoroughly capable of running on actual long-distance railway service at a high speed. The experiments had been discontinued at the beginning of December, 1901, partly owing to the winter and partly owing to the fact that the permanent way had not been equal to the demands made upon it. The line was very light, the rails weighing only 67 lbs. per yard, and it was insufficiently ballasted: consequently when it was relaid and put into better order the figures would no doubt be modified considerably as far as the tractive resistance was concerned. It would be seen that the tractive resistance in the experiments had been something like 10 lbs. per ton or a little more. Mr. Raworth had raised the objection that the collecting-gear used on both the cars would not be suitable for British conditions. That was perfectly true; but of course in North Germany there were no tunnels, and except in towns there were practically no bridges, and consequently it had not been necessary to consider the question of the cars, with their collecting-apparatus, having to pass any particular load-gauge. It did not seem impossible, however, that the system might be modified so as to meet the conditions in England. In the Paper reference was made to the Burgdorf-Thun railway in connection with the speed of the three-phase motors. The motors on the car and on the locomotives were somewhat different in type and differed considerably in size. The motors of the car were rated at 60 HP., at 600 revolutions; those on the locomotive were rated at 150 HP., at 300 revolutions. The wheels on the car were smaller, 37½ inches in diameter as compared with the locomotive-wheels, 49¼ inches; and the gear was different, the car gearing being one-third, while the locomotive was fitted with two gearings. The locomotive was required to run at a speed of 11¼ miles per hour, which was about half the speed of the passenger trains, for the purpose of hauling goods; but it had been considered that the locomotives should be capable of hauling the passenger trains, and therefore they had to be able to run at the higher speed. Consequently, they were fitted with two sets of gear, one a gear of 1·88 for running the passenger service, and the other of about twice that, 3·72, for running the goods trains. He did not think it was a question of synchronous speed at all; the conditions of

Mr. Dobree. the two things were entirely different, and the fact that the speed of the goods trains was half that of the passenger trains was a matter of chance.

Mr. Hudleston. Mr. F. HUDLESTON wished to draw attention to the figures for the efficiency of the Central London Railway given by the Authors. Mr. McMahon had already pointed out that there must be something wrong. The Central London Railway in its regular working had really an average efficiency of transmission of somewhere about 85 per cent., and that could be found from the curves of efficiency which the Authors gave, assuming of course an allowance for the heavier amount of plant run at the sub-station over and above that run at the power-house. The reason was that in all sub-stations a considerable amount of plant had to be run to take care of the peaks in the load, owing to the heavy draft made upon the sub-station at times by the local conditions of trains. At sub-stations the capacity of the plant in use was some 15 per cent. or 20 per cent. above the output at the generating-station. Experiments had been made on the Central London Railway during the year of maintenance in which he had had to watch it, and it had been found that the average efficiency of transmission was about 85 per cent. With that knowledge he had been a little puzzled to see the figures in the Paper, and he had taken the trouble to analyze them, with the following results. The sub-station output given at 3,833,207 Board-of-Trade units for 3 months, was as nearly as possible at the same rate as had been obtained during the experiments up to the end of July, 1901. The gross amount divided by the train-mileage gave the Authors' figure of 95 watt-hours per ton-mile; but, as Mr. McMahon had pointed out, the Authors had forgotten to deduct the energy used for lifts and lighting, which amounted to 20 or 22 per cent. of the total. That would reduce the output at the sub-station to about 73 watt-hours per ton-mile, which was a little above the average. Calculating from the gross output of 3,833,000 Board-of-Trade units on the efficiencies he had mentioned, it would be found that the output of the main station should be nearly half a million units more, and he could not help thinking that the figure given, viz., 4,113,000, was a clerical error for 4,613,000. He suggested that the Authors should have their figures corroborated before they finally appeared in the Proceedings of the Institution. If such an efficiency as 93 per cent. were really obtained on the Central London Railway the coal-bill would not amount to anything like 5½*d.* per train-mile as it did at present.

Mr. W. M. MORDEY, in reply, expressed his gratification at the attention and consideration which had been given to the Paper, and remarked that he was glad to have been the means, with Mr. Jenkin, of bringing about such a useful discussion on the subject of electrical traction. Before going to the commencement of the discussion, he desired to say a few words in reply to those who had just spoken. It was not possible to reply to five nights' discussion in half an hour or so; he could only deal with a few points, and would then ask his colleague to take up one or two other main points. He was very glad to have heard Mr. McMahon's practical contribution to the discussion, and thought that the figures Mr. McMahon gave could not fail to be of great interest. On the whole they confirmed the views expressed in the Paper; but Mr. McMahon had questioned a figure as to the loss in starting. In the Paper it was stated that about two-thirds of the total power was lost at the moment of starting, but Mr. McMahon reduced that to 5½ per cent., instead of 66 per cent. That was a large difference, but he thought Mr. McMahon had taken the energy for the whole run, and not the mere power at starting. If Mr. McMahon would look into it again he would find that the figure given in the Paper was right, within a small percentage, under ordinary conditions. The distinction was important, not so much on account of the value of the energy as on account of the plant required at the generating-station, to meet the heavy peaks. There was a great saving secured in the amount of generating-plant in a system that could be worked without heavy peaks, as compared with all present methods, although the actual power exerted on the train might be the same in the two cases. He agreed that had Mr. McMahon the same conditions as on the Central London Railway as regarded a good midday service he would make a still better showing. He had been pleased to hear Mr. McMahon say a few words of approval of the Authors' recommendation of a variable-ratio gear as apparently the only way of getting over the difficulty of rapid acceleration without an enormous plant in the generating-station and on the motors. He thanked also Mr. Hudleston for correcting the figures with regard to the Central London Railway. Mr. Hudleston had really not corrected the Authors, but the Central London Railway Company, which had supplied the figures. They had been put into the Paper as they had been given, but no responsibility was accepted for them, and he thought it would be seen by looking at the terms in which they were referred to that the Authors had had grave doubts as to their accuracy. Personally he did not Mr. Mordey.

Mr. Mordey. think an over-all efficiency of 93 per cent. could possibly be obtained out of the whole system, one part of which only had a maximum efficiency of 93 per cent. He was also interested to see that there was a possible leakage of 500,000 units in the figures that had been given, and he would ask Mr. Cuningham to go into the matter and say whether the figures he had sent of the actual results had been mis-stated by some clerical error.[1] Going back to the commencement of the discussion, he had been much surprised to hear the constant continuous-current system brought up again. It had been tried in England only once, and he did not know that it had been tried anywhere else. He remembered the Northfleet tramway working in 1889 on that system, a small affair, $3\frac{1}{2}$ miles long, with three or four cars and very small power. But since then, although the system had been repeatedly mentioned and no doubt carefully considered by a good many engineers, it had never been taken up. It was not referred to in the Paper, because the Authors had considered it dead and buried; but Lord Kelvin—for whose kind and appreciative remarks he wished to express his sincere thanks—had asked for a reconsideration of it, although he had put the suggestion forward quite in a tentative way, and had not expressed any strong opinion on it. Mr. Siemens had gone a little farther, and had said the system had not had justice done to it; and Mr. Swinburne had gone still farther and had said that it would do nearly everything. There was a great deal in it, and there was a great deal in most systems; every system had some good qualities. But in the questions dealt with in the Paper the Authors had had to look at the whole thing broadly. It was not a matter of picking out a system that had one or two good qualities. It was necessary to pick out a system which contained the really essential points for a general comprehensive system, even if it possessed perhaps one or two bad qualities. He thought the revived constant continuous-current system had one or two good points, but it had many very bad ones. The good points were that it could be used to return energy, and that wasteful resistances were not necessary at starting; but it had no other good points. In the first place it required two wires, and that

[1] As mentioned in footnote 1 to p. 81, Mr. Cuningham has since kindly informed the Authors that the values given for the main-station output and sub-station output include all power used, and are correct as obtained by the Company's wattmeters. He adds that, for the 6 months ended 31 December, 1901, the sub-station output is 90 per cent. of the main-station output.—*July*, 1902.

alone was almost enough to put it out of court: but they were not two simple continuous wires only, such as might be used with a constant-pressure system; they were wires that were constantly changing in pressure, and they were cut into short lengths of different pressures all along the line. It was a system which required that there should be only one train on one section. This would slow down both trains, and would not be good even for automatic-block purposes. If trains did not pass from one section to another simultaneously, two trains might be in one section, and then it would be a constant-current system no longer; each train would get only half the current. Further, a limit to the electromotive force or to the current, or to both, would soon be reached. It had all the evils of the old and discarded series lighting-system. When the limit was reached that would work, say, half a dozen trains, it would be necessary to begin again from the very beginning, starting with a new generator at the generating-station, a new line throughout, and a new set of connections for another system. It was quite impossible to work anything like a large railway-system on that plan; it did not lend itself in the least to what was a very important matter, the gradual growth from small beginnings, as the system extended to branch lines and to a greater length of main line. Another drawback was that transformation was impossible except by rotating machinery. One of the most important difficulties of all would be in the generation and regulation. The problem of getting a constant continuous current, even when that current was only 10 amperes, was a very difficult one indeed; to make a generator to give 5,000 kilowatts with 5,000 volts or more, with several hundred amperes, was, as far as he knew, impossible with present knowledge—at least, to work successfully under the severe conditions required for electrical traction. Mr. Hammond had remarked that the constant continuous-current machine was to-day where it had been 18 years ago. Such machines would not work in parallel. The difficulties of large machines with varying very high voltage, varying load, moving brushes and sparks at the commutator were almost insoluble with a few amperes; but with thousands of horse-power the problem presented difficulties far in advance of the present means of solving them. Again, the rail could not be used as a return, and a return conductor near the rail or nearly at earth's potential could not be used. In fact, all the series, multiple series, and group systems, had been discarded in ordinary tramway work, in railway work, in lighting and power work, and had given place to the simple constant-pressure supply, with either two wires or Mr. Mordey.

Mr. Mordey. three wires, and either continuous or alternating current. Whatever complication there might be, an endeavour ought to be made to keep it off the conducting line, whether that was overhead or on the ground. The conducting line should be as simple and as plain as possible, and that was only possible, as far as the Authors could see, by some constant-pressure system, and was best met with the single-phase system with one wire. There was no particular virtue about a constant current or a constant torque; a variable current and a variable torque were better. At present constant voltage and a variable current were used, but if variable voltage and a variable current could be used on the train so much the better; and that was what could be obtained by the variable-ratio transformer system, the advantages of which the Authors had been led to see by carefully considering the essentials for general railway work. The evils of constant current were greater than the evils of constant voltage. Coming to the broad question of alternating- or continuous-current systems, there was no such thing as continuous current, except with the old "Faraday disk" machine, which gave a continuous current without commutation; but in spite of much study, that machine remained to-day substantially where Faraday had left it. Every continuous-current generator produced alternating currents, and every continuous-current motor used alternating currents. A commutator was used at the generator to turn the alternating current to a continuous current, and a continuous current was used along the line. When the motor was reached another commutator was used to turn the continuous current into an alternating current in the motor, and it was an alternating current that did the work. This seemed to him to be going a long way round. What it was desired to do was involved in the alternating current, and he thought it was possible to evolve it from that. In continuous-current working it would be seen that it was only on the line that there was a continuous current at all. The double commutating process was really a transformation process which was accompanied by a good deal of loss, fully 2½ per cent., or quite as much as need occur in a double transformation of pressure in large alternating-current transformers. As to the supposed complexity of the single-phase method, he thought Mr. Webb's criticisms were hardly justified. Dr. Kennedy had rightly pointed out that the complication of the ordinary locomotive was far greater than that of a machine of the electric-motor type. If a working-drawing of a horse had been placed upon the wall some of the members present would no doubt have argued that it could not possibly work! He was glad to have had from Mr. Cottrell the

very interesting and useful diagram showing the improved acceleration on the Liverpool Overhead line, and to have heard Sir Frederick Bramwell's practical remarks on that subject. Opinion was being rapidly formed on the question of the importance of high acceleration and its practicability. It might be remembered that Mr. Blathy, in the arbitration case, had stated that Messrs. Ganz and Co. at first had taken 1·8 foot per second per second as the maximum acceleration, but had found afterwards that 3 feet per second per second was quite common, and finally had adopted 2 feet 6 inches as long as the motors were in cascade and 1 foot 4 inches afterwards. Mr. Cottrell's diagram (*Fig. 10*) confirmed what Sir Frederick Bramwell had mentioned; it showed an acceleration of 4·2 feet and a retardation of 4·8 feet per second per second. That had increased the mean speed on the Liverpool line, so that the journey now took 12½ minutes instead of 19 minutes; but the result was only obtained at a heavy cost. It would be seen from the diagram that there was a maximum of 700 amperes, 350 kilowatts, which was about 600 I.HP., of which, however, only a small portion was actually usefully applied on the train; it would also be seen that there were large variations, due to the methods of control, in the current and in the acceleration. Those were the evils of the series-parallel controller. The maximum shown on the curve was at least three times as much as it need be with a proper variable-ratio system of working; in other words, the plant in the station might be one-third as much, so far as the peaks were concerned, if it were not for the inherent defects of the constant-pressure system without some variable-ratio method. With regard to acceleration, it appeared to be recognised as important that at the very beginning and at the very end the change of acceleration should be gradual. The train should not be started suddenly or brought up dead. He remembered that on the District Railway some years ago a brake had been tried which made passengers almost sick in a run of a few miles; the train had stopped quite dead, the brake acting very suddenly. The question of alternating-current electrolysis had been raised by several speakers. Continuous-current electrolysis had been greatly overrated. It was now known that where the Board-of-Trade regulations were complied with there was not an iota of evidence of any electrolysis having taken place. The expectations of theorists in this matter had been entirely contradicted in practice. Practical results had shown that the amount of current passing produced in some cases only about 4 per cent. of the action estimated on a theoretical basis. That was due to the fact—not recognised until recently—that the Mr. Mordey.

Mr. Mordey. earth acted as a conductor and not as an electrolyte; thus laboratory tests had led to conclusions which were entirely contradicted by practice. It had been stated that alternating-current electrolysis was worse than continuous-current; as a matter of fact it did not seem to be as bad—at least, with such low current-densities as were likely to be met with in railway practice. It only began with a current-density that would give enormous deposition with continuous currents. In the experiments of G. Mengarini on the electrolysis of liquids,[1] it had been shown that until a density of 4 amperes per square inch was obtained there was no electrolysis at all. With continuous currents there would be large volumes of gas coming off with such a current-density as that. In any case the question should not affect practical railway-working, because there was little doubt that, in the future, railways would be worked, not by a conductor earthed all the way along, but by a conductor earthed at only one point; and then electrolysis would not come in at all. Something had been said about the difficulties of collecting the current from overhead. He did not for one moment wish to minimize those difficulties. They might be very serious, but whatever they were they would be very much less with one conductor than with two, and much less with two conductors than with three. It seemed to him that if there were difficulties in collecting current, that was only another reason, and perhaps a sufficient reason in itself, for adopting a single wire for the purpose of carrying the current. With very high tension the difficulty would be much less than it had been with 500 volts, as the current would be much less. It was not even necessary to have continuous contact. He believed that at Zossen, even when the trolley did not touch the wire, the energy was conveyed; there was a spark—not a very large one—and the energy traversed the small air-gap without causing any trouble. For ordinary working he did not think there was any difficulty. He had travelled on large heavy tramcars in America running over 50 miles per hour—on lines which were railways rather than tramways—day in and day out, without any difficulty beyond ordinary wear and tear. With regard to the recommendations in the Paper, the Authors did not wish to emphasize them too much; they wanted the facts to speak for themselves. But he

[1] *The Electrician*, vol. xxvii. pp. 304 and 334. It appears, however, from this Paper that, at higher densities than that given above, the action on the electrodes may be more destructive than with continuous currents; *e.g.*, even platinum electrodes may be acted on and destroyed. See also, R. Malagoli: *L'Éclairage Électrique*, vol. xiii. p. 255.—W. M. M.

thought the very small amount of adverse criticism on the conclusions to which the Authors had been led showed that there was not much to be said against them. He would be quite happy to wait 10 years to see whether those conclusions were justified or not, and he would do so with every confidence. He had just heard from Mr. E. Huber, of the Maschinenfabrik Oerlikon, that his firm were making a 700-B.HP. locomotive to work with a single-phase variable-ratio system at 15,000 volts—a four-axle locomotive weighing only 42 tons.[1] Whether electricity would be used on railways or not it was not for him to say, but it appeared that the limits of speed and acceleration had been reached with steam. Reciprocating action appeared to be objectionable. No one had proposed to put a steam-turbine locomotive on railway lines to see if that would get over the difficulty. It would avoid reciprocating motion but not the weight difficulties. For short lines electricity had come; for lines of moderate length it was there if wanted; for longer high-speed lines—for running services between busy towns at extra high speeds—it was the only thing that would answer the purpose. Whether it was coming for main lines or not he would not say, but he thought those who argued that it was not were rather like King Canute—with this difference, that he had known the flowing tide would not stop, and they perhaps did not. Mr. Mordey.

Mr. Bernard M. Jenkin, in reply, pointed out that the Ward-Leonard system was really a transformer from constant pressure to constant current, if it was desired to keep the current constant; but with the system in the Paper it was possible to improve upon that, because the current could be varied as required. There were all the advantages of a constant current in driving the train, without any of the disadvantages of generating, transmitting and collecting it on the train. As to the question whether or not it was worth considering the working of main lines, a number of railway engineers had spoken of electrical working for suburban lines as being extremely good, and had expressed the opinion that it was really the only way to work suburban traffic; but they had gone on to say that it was not the way to work main lines, and need not be considered at the present time. It appeared that if electrical working was admitted to be necessary on suburban lines it meant that the suburban traffic was going to extend; and the use of electricity would enable the suburban traffic to be worked much more quickly and to greater distances from towns. Very soon the suburban traffic of neighbouring towns would touch, and the Mr. Jenkin.

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[1] See also p. 178.—Sec. Inst. C.E.

Mr. Jenkin. towns would have to be connected by a line running from the centre of one to the centre of the other, and worked at high speed. That had already happened at Liverpool and Manchester, and it would really be much better to make the high-speed connecting line an extension of the suburban traffic than to put up a line of entirely different construction, which had to be kept quite separate and was unable to take any of the suburban traffic between the two centres. A line to Brighton had already been discussed, and there it would appear to be much better for the existing railway companies to equip one of their lines electrically and to run high-speed trains, than to let others build a line the whole way and work it electrically. The Metropolitan Railway was being equipped, a line on which three of the large railway companies, the Great Northern, the Great Western, and the London and North Western, ran trains, and those companies would have to consider the question of the electrical driving of the trains, and would probably have to equip the lines outside the Metropolitan district on which they ran—that was, they would have to equip a portion of their main lines as far as distributing the power to the trains was concerned. Surely it was much better to choose a system of equipment that would be suitable for the main-line working when it came, than to put in a system which would not be suitable for running high-speed long-distance trains. If it was possible with a little forethought to arrive at some system of distributing the power to the trains which could be extended and used as the traffic extended, that was preferable to saying, "This is good enough for suburban traffic; we will not consider anything further." Then there was the question not only of the lines in England, but of the lines in the Colonies and abroad. There were rumours of a high-speed railway to be built in one of the Colonies, and foreign firms in Germany and elsewhere were already preparing their tenders and had been trying experiments. Surely it was not wise for English manufacturers to sit down and say it was not worth while to consider the matter. If England desired to compete, thought must be given to it. The Americans had been allowed to go ahead with tramway work, with the result that, when tramways had been taken up in this country, the Americans had had a good deal of the work before the English manufacturers. The same thing had happened with three-phase transmission, Germany and Switzerland having developed it and reaped the first fruits. England, however, had made as good single-phase plant, and as early, as any other, and perhaps it would be worth while thinking

whether it was not possible to design railway plant to compete with other countries. The question of cost of working had been raised, although it was a question entirely outside the Paper, and one that had to be considered on the merits of each case. Colonel Crompton had spoken of a sub-station every 7 miles on a line 180 miles in length, which meant twenty-five sub-stations; and Mr. Horace Bell had mentioned that the whole traffic of that line could be worked by ten locomotives. Each of those sub-stations might well have to meet the demands of two trains working in opposite directions. Therefore there were two-and-a-half times as many stations as locomotives, and perhaps twice as much plant in each sub-station as was required to drive one train. In that case there would be five times as much plant in the sub-stations as there would be if it were put on the locomotives. Several speakers had mentioned the large amount of additional plant required if the transformation was done on the locomotive instead of in sub-stations. The statement appeared vague, as they had not compared it with any other system. If they had compared it with the composite system it would have been found that it was likely to be less instead of much more. For any given number of trains there must be sufficient power at the sub-stations to transform the whole power required to drive those trains. Whether it was better in the sub-stations or on the locomotives he did not say. It would not necessarily be more in one place than the other; but it would probably be more in the sub-stations than in the locomotives, because a sub-station might have to meet a large momentary demand from a number of trains collecting at that point. The transforming plant on the train could never be called upon to supply greater power than was required by that one train. There were many other questions besides that of cost which had to be taken into account in considering the working of lines electrically and by steam. In regard to speed, for instance, there was no doubt that much higher speeds could be attained by electrical driving than by steam, and far steeper gradients could be climbed, as Sir John Wolfe Barry had pointed out in referring to the experimental electric train, which had taken up a 1-in-43 gradient not only the train itself, but also the steam-locomotive. Then there was the question of acceleration. The maximum weight on the driving-wheels had already been reached by steam-locomotives, but with electrical driving it was possible to distribute the driving power throughout the train, and therefore much greater power could be applied to the train without increasing the weight Mr. Jenkin.

Mr. Jenkin. on any one pair of driving-wheels and the consequent wear and tear and stresses on the permanent-way. There was also the absence of smoke and noise, and other points which were decided advantages. The cost of transport per ton-mile might come out heavier—he did not say it would be more, because he had not worked it out—but that did not condemn the system at once, because if it was possible to double the capacity of a given line by increasing the speed it might be well worth paying a great deal more per ton-mile for transport. Transport by sea no doubt cost a good deal less per ton-mile, but still things did go by rail. The question of weight had been urged as a great objection to the placing of the transforming-plant on the locomotive. Some points in connection with that matter might be mentioned. The weight-efficiency apparently had not been carefully considered so far in railway work: the figures were rather astonishing. On the Liverpool Overhead and the City and South London Railways the dead weight of train per seat was about 700 lbs. On the Waterloo and City and Central London Railways it was approximately 1,000 lbs.; on the Metropolitan Railway it was about 900 lbs.; but with main-line express trains it jumped from 700 lbs. and 1,000 lbs. to 3,800 lbs. per seat. Under such conditions a difference of a few per cent. more or less in the weight of the machinery of the locomotives seemed a little beside the question. It would be found that a dead weight of 30 tons was added to a train for the kitchen of a dining-car alone; perhaps if the cooking were done electrically the whole of that weight might be saved and put on the locomotive. The following Table (p. 167) showed that at the present moment there was an electric locomotive which compared extremely well with the express steam-locomotive. Taking the high-speed car, which, however, was not built to haul heavy trains on a main line, it might be seen how it worked out if put to haul an express train. The first column of the Table related to an ordinary express train; the second column to one of the high-speed cars at Berlin; the third column to the motor-car on the Valtellina line, not the whole train; and the fourth column to an express train formed of a motor-generator car based on the Berlin car and carriages as in the first column. The maximum horse-power was three times as great as in the steam-locomotive. There was 20 per cent. instead of 10 per cent. of the total weight on the driving-wheels, although the maximum weight on any one pair was practically the same as in the steam-locomotive. It would be seen that it was not an absurd thing to talk about the electrical haulage of main-line

trains. He did not say that was the right way to drive a train on a main line, but it showed the thing was quite possible, and that the weights and other details were not ridiculous. The question of variable speed was an important one, as had been pointed out by Dr. Kennedy. With three-phase working of trains the disadvantage of having to run at a fixed speed was very great indeed. At present, a three-phase motor coupled direct on the axle meant running at a speed at which it was running synchronously, if it was to work efficiently and satisfactorily. That had been a great disadvantage on the Burgdorf-Thun line, as had been pointed out by Professor Carus-Wilson in a Paper[1] before the Institution of Mechanical Engineers: he mentioned that up the steep gradient on that line (1 in 40) the motor-car could only take one trailer because it had to run at full speed; but on the level it could take five trailers. If its speed could drop from Mr. Jenkin.

WEIGHTS OF STEAM AND ELECTRIC TRAINS.

——		Steam Locomotive.	Berlin A. E. G. Car.	Valtellina Car.	Motor-Generator, Car and Train.
Locomotive and tender	tons	90	..	..	..
Motors	,,	..	13	15·2	13
Remainder of electrical equipment	,,	..	16	6·9	46[1]
Car and bogies	,,	..	48	31·5	48
Carriages	,,	250	..	..	250
Total weight of train	,,	340	77	53·6	357
Passengers carried		200	50	30	250
Weight per passenger	lbs.	3,800	3,450	4,000[2]	3,190
Weight on one pair of driving-wheels	tons	17	13	13·4	17·8
Total weight on driving-wheels	,,	34	51	53·6 26·8	71·2
Ratio of weight on driving-wheels to total weight (per cent.)		10	67	100 50	20
Normal horse-power		500	1,000	300	1,000
Maximum horse-power		1,000	3,000	600	3,000
Horse-power per ton of train (normal)		1·47	13·0	5·6	2·8
Horse-power per ton of train (maximum)		2·94	39·0	11·2	8·4

[1] Thirty tons allowed for motor-generator, which is a little more than twice the weight of the motors.

[2] This figure does not take into account the trailers that would be hauled by the motor-car. A motor-car is also built for this line weighing 50 tons and carrying fifty-six passengers, which reduces the weight per passenger to 2,000 lbs.

[1] Proceedings Inst. Mechanical Engineers, 1900, p. 435.

Mr. Jenkin. about 24 miles per hour to about half that speed when running up the incline, it could take those five trailers with it. Therefore the very fact that it had to run at the constant speed, and take a great deal of power in going up the gradient, limited the capacity of the line considerably. On the Valtellina line there was a possibility of altering the speed by putting the two motors in series, and no doubt that might be of great importance. He had heard recently of some experiments made by Von Dobrovolsky for the Allgemeine Elektricitäts Gesellschaft, of Berlin, with a similar system, but using two three-phase motors of exactly the same design, and not as on the Valtellina line, where one motor worked at much lower pressure than the other, and was used only up to half-speed. Beyond half-speed one of the Valtellina motors had to remain idle, and was of no use for full-speed work; but in the experiments made in Berlin two motors had been taken of exactly the same design, coupling the stator of the first motor to the supply pressure, the rotor of that motor to the rotor of the second motor, and the stator of the second motor to the starting-resistance. The two motors were coupled in series at starting, and were run in that way up to half-speed; then they were put in parallel. The motors being identical that could be done. The stator of the second motor could be connected to the supply lines, and the two rotors were connected to the starting-resistances during the rest of the acceleration up to full speed. In that way there was an arrangement of series-parallel control with the motors on the three-phase system exactly similar to the arrangement with continuous-current motors in the usual way. He thought it was absolutely necessary that high pressure should be adopted for transmission on railways, certainly if long railways were to be worked. The cost of conductors for a low-pressure system was too great, and there was also the difficulty of collecting large currents. With a sufficiently high pressure the current to be collected could be reduced to quite reasonable dimensions. The difficulty in collecting arose out of the strength of the current, and was not due to the pressure; the pressure could take care of itself. Working at 10,000 volts, as was being done on the Berlin high-speed line, only meant collecting a current which was just the same in amperes as that of an ordinary street tramcar; and consequently the trolley-wires were of about the same size. If, however, there was 3,000 HP. on the train, and the current was collected at only 500 volts, it became quite unmanageable, and that was probably why the trouble had arisen at Baltimore. The question of danger was, he thought, overrated. There was no doubt

danger in having a high pressure on the overhead wire; but surely the way to deal with the matter was not to limit the pressure and reduce it until it was not dangerous. In the ordinary steam-locomotive the boiler was under high pressure and was a dangerous thing; still, it was taken into tunnels underneath houses, although it might blow up the tunnel by exploding, and might kill everybody in a station. But it was not said that the pressure must be limited until, if the boiler did explode, it would not hurt anyone: the boiler was properly constructed, and the risk was taken. High pressure must be used on long-distance lines, and the line must be dealt with in such a way as to make it safe: that was the right way to go about the matter, and not to limit the pressure. Another essential difference between suburban traffic and main-line traffic was that in the latter the length of line was very great as compared with the number of trains, and therefore the equipment of the line must be simple and cheap. On a suburban line the cost of the line-equipment was not a matter of great importance, because there were a large number of trains, and its cost in relation to total cost was not so great; but on long lines the equipment was far more important and its maintenance was a far more serious problem. Therefore it was necessary to try to make the overhead distribution as simple as possible, and that certainly could be done by one wire far better than by more than one, and by making it a high-tension line with as few switches, and as little transforming-apparatus, or other complication, as possible. With a constant current the line had to be divided into sections, with switches on each section, and a great deal of complication was introduced, as well as the necessity of having two wires, which, having both to be at a high potential above earth, must both be overhead. It had been stated that with an overhead wire it would be impossible to work shunting-yards, but on that point there was a misunderstanding. With one overhead wire the whole of the conductors were at one and the same potential, and it was possible to connect them parallel. There were no insulated or dead sections. It could be all at one plane over the railway, and the current could be collected probably by some scraping or slipper device. There was no difficulty at the points and crossings, as there were no points to be shifted. The collector had not to be made to go one way or the other, as it simply followed the train. In fact the very system was being adopted largely on the Continent for goods yards, where electric locomotives were being used for handling Mr. Jenkin.

Mr. Jenkin. trains in goods yards without driving the whole line electrically. With steam-locomotives on the main lines, they put in electric shunting-locomotives with a single overhead wire and the device worked extremely well. There was no insuperable difficulty in doing it, such as had been referred to by Mr. Webb. It had been suggested that the trolley-wire or conductor should be placed at the side of the line, but that at once involved difficulties at points and crossings. If the conductor was on one side, it was necessary, where lines branched off or crossed, to have gaps in the conductor to let the other line through. It was simpler to keep the conductor over the top of the train and to collect the current from beneath it.

Correspondence.

Mr. Behr. Mr. F. B. Behr remarked that the Authors' interesting Paper, though containing a large amount of valuable information and setting forth in a striking manner the different systems of electrical traction, seemed to proceed on the assumption that, if sufficiently perfect electrical machinery could be designed, the question of working the large railway systems of Great Britain, such as the London and North Western or the London and South Western Railway, by electricity, would be solved. To him it appeared that the first point to be considered was whether it was likely, assuming that the arrangements for electrical working were sufficiently perfected, that a complicated system of railways such as those of England could be worked entirely electrically. He considered this was absolutely impracticable, unless central generating-stations and conductors could be dispensed with altogether; and this had been tried in the Heilmann locomotive, and had proved a failure. Even if the most perfect system of electrical traction involving central stations and conductors was applied to any one of the great railway systems, it must end in absolute financial failure. In order to pay commercially, electrical traction had to deal with as nearly constant loads as possible, and must employ the total capacity of the generating-station as fully as possible. Sudden and exceptionally heavy demands on the traffic could not be dealt with economically by electrical traction. Considering, for instance, the London and South Western Railway, with its numerous race-meetings, when many thousands of people who did

not travel on other days had to be carried during one or two hours Mr. Behr. of the day, and supposing there were sixty such days in the year; if the electric station and the conductors were to be able to cope with such special traffic, the initial capital expenditure would evidently be enormously increased, and a great deal of it would be unproductive for the larger part of the year. Such instances could be multiplied indefinitely, *e.g.*, the traffic on Derby Day, the Saturday and Sunday excursions on the London, Brighton and South Coast Railway during the summer, the special trains for the Liverpool Grand National. In fact, it might be said that on all great railways there were some very large and sudden increases of traffic which taxed the companies, even under the existing conditions, to the utmost, and could not be provided for with economy by means of central power-stations and conductors. Further, the difficulties of shunting in complicated goods yards seemed absolutely prohibitive: how could places like Clapham Junction or Willesden Junction or Crewe be worked electrically? On the other hand, it was hoped by some that the injury done to the railway companies in their suburban traffic by the competition of electric tramways would be counteracted by applying electricity to the railways; but would that actually be the case? The injury was really due to the facts that tramways went nearer to the destinations of many people than the railways could possibly go, and therefore it was in many cases more convenient to use them; that the fares were comparatively cheaper; and that there were more frequent departures. He did not think any of these causes would be counteracted by electrifying a large railway system. On the contrary, he believed that it would prevent the possibility of increasing the number of trains, and certainly it would not enable the company to lower its fares to pay for a large increase of capital. However, the nucleus of more or less constant traffic which existed in every great railway system could be dealt with by electrical traction; and he believed that in each case the complications on the existing systems, which gave rise to a great deal of extra cost and at the same time prevented the greater frequency of trains, could be reduced. By removing this more or less constant traffic on to special lines worked by electricity, the competition of the tramways would be met in a large measure, the receipts of the railways would be increased, and the expenses would be reduced; leaving a large portion of the traffic to be handled by the present rolling stock and engines, which would be done more advantageously by those means than by electricity. In conclusion, he

Mr. Behr. might point out that in order to suggest any practical amelioration of the existing railway systems it was absolutely necessary not to recommend something which would start by rendering a large portion of the existing capital useless and adding to it an immense amount of new capital; because, even if there were some great advantages in one way resulting from such a recommendation, the financial feature of it would render it ineffective commercially: whereas by bringing to the aid of the present traffic arrangements electrical traction as an auxiliary for such portions of the traffic as could employ it with advantage and economy, the comparatively small amount of new capital necessary would be amply repaid by the economy, speed, and frequency of trains which would follow; and for that purpose the existing machinery for electrical traction seemed quite sufficient.

Mr. Brown. Mr. C. E. L. Brown, of Baden, remarked that he quite agreed with the opinions put forward by the Authors; but there were one or two points on which he would like to offer some comment. It was stated in the Paper that with polyphase systems lost time could not be made up, implying that the continuous-current system was superior in this respect. All railway plants had to be calculated for a certain speed; in the case of polyphase systems the normal speed only differed from the maximum by a small fraction, that was, the speed was practically constant for all loads; whereas in the case of continuous-current systems the speed was highest at light loads and with full pressure, and lowest at heavy loads. It was obvious that the principal need of making up for lost time on railways arose when the traffic was heavy, involving delays owing to longer stops at the stations. But just when a high speed was required to make up for lost time, the continuous-current motors failed, as they ran more slowly, the carriages being heavily loaded, and possibly the pressure lower than usual. It followed that a continuous-current railway, working under economical conditions, namely, without wasting power in rheostats at the normal speed, was inferior to a polyphase railway, which adhered to the scheduled speed in times of heavy traffic and ensured punctuality. Under ordinary conditions lost time could be made up only on down gradients; this could be done not only on continuous-current railways, but also on polyphase railways. Moreover, the result arrived at by the foregoing theoretical considerations was confirmed by his experience on the Burgdorf-Thun line, which showed that it was easier to keep to scheduled time regularly with constant speed than with variable speed, as illustrated by the

steam-hauled trains which ran on the same metals. In connection with the Authors' remarks on three-wire systems, it might be of interest to mention that there was an example of a three-wire 1,000-volt tramway near Grenoble, and that another line was in course of construction in the same neighbourhood. Coming to the conclusions arrived at by the Authors, he quite agreed with them that a composite system, and especially one using a high-tension single-phase transmission-line combined with a motor-generator on the locomotive, had many points in its favour. He considered it a great advantage that no rheostats were needed, giving a perfect and economical control for the full range of speed. He would like to point out that Messrs. Brown, Boveri & Co. had used this system of control as early as 1891 for the first (800-HP.) Heilmann locomotive, and that such good results had been obtained therewith that the two later Heilmann locomotives, each of 1,200 HP., had also been equipped with it. As a further consequence the firm had employed the system for a trolley-locomotive in St. Germain in 1895. This locomotive had carried a motor-generator consisting of a continuous-current motor wound for a tension of 500 volts to take current from the line, coupled to a dynamo generating current at a variable pressure of from zero to 400 volts. In addition to these applications, they had studied, in 1897, the question of employing the same system for the Burgdorf-Thun Railway; they had intended to transmit the energy as single-phase or three-phase high-tension alternating current and to place a motor-generator on the locomotive. But it had been found that the locomotive would become too heavy; and so, although quite appreciating the advantages of the system, they had decided not to employ it in this instance. They were of opinion that the great weight which the locomotive must necessarily have was the main drawback of the system. They had, however, lately had occasion to reconsider the idea, as they now saw a means of reducing the weight by employing high-speed machinery, with which their experience of steam-turbine work had rendered them more familiar. Mr. Brown.

Mr. A. B. Chatwood observed that he had read the Paper with great interest, but he was sorry that it had not been rendered still more comprehensive and complete by the consideration of the advantages to be gained by electrical over steam traction. Several times during a number of years he had suggested that advantages were to be gained by electrical traction quite apart from those of generation of power in bulk by fixed engines; these advantages being that owing to the absence of reciprocating parts Mr. Chatwood.

Mr. Chatwood. and to the continuous nature of the torque obtained with electromotors, the power would be more efficiently applied between wheels and rails, the speed would not be limited except by considerations outside the engine, and the life of the rolling stock would be increased. He had suggested as a profitable experiment the mounting of a small generating-station on the train itself, in order to ascertain how far these advantages would go towards compensating for the losses in efficiency due to the two extra energy-transformations.

Mr. d'Alton. Mr. P. W. D'ALTON remarked that he proposed to touch only on one or two concrete points immediately germane to the detail of the Paper, and in no sense to deal with it from an abstract point of view. In the earlier part of the Paper some comparisons were established between the system in use on the City and South London Railway and that of the Central London Railway; and, judging by the diagrams, it appeared to him that the latter was superior to the former, in that it required a much smaller amount of running machinery. In the Central London system a high-tension polyphase machine took the place of four 500-volt dynamos required for the five-wire system of the City and South London Railway, and three rotary converters were used in place of three balancers and four reducers. At the same time a large saving in cables was effected, owing to the increased pressure of the Central London system. The capacity of the rotaries used in that system was 900 kilowatts, and although there were in all seven of these machines installed, they had never given a moment's trouble; while the cost of conversion from three-phase to continuous current was wonderfully small—about 0·025*d.* per kilowatt, including all charges. The "disadvantages" of the composite system were, he thought, somewhat exaggerated by the Authors. As shown, the skilled attendance was not a serious drawback; static transformers could be made which practically never failed, and cost little or nothing in upkeep; and speaking from his own experience, he had no hesitation in saying that, well-designed and properly treated, rotaries gave no trouble at all. It was not easy to reach their limit of ill-treatment, for they would stand an astonishing amount of overload, provided there was ample copper in the primary of the system, without showing any signs of overheating or coming out of synchronism. As an example, it might be mentioned that one of the rotaries at the Marble Arch sub-station had given 23,000 kilowatts in 17 hours without any sign of distress, save a comparatively small increase in temperature. Such machines were self-starting, and

Mr. d'Alton.

motors for running them up to synchronism appeared to be superfluous. On the Central London Railway the first machine was started as a three-phase motor, and from it the others were run up as continuous-current motors, being synchronized in the usual way as required, and, as he had stated, without hitch or any polarity trouble. An experiment had been made one Sunday morning, before the traffic began, by starting two alternators at the power-house, putting five rotaries in parallel with them in the usual way, and then starting a sixth rotary from the three-phase side at the Post-Office sub-station, which was about 6 miles from the power-house. The effect of this had been to reduce the voltage to about 3,000 volts, but no machine had come out of step, and as the machines had come up to synchronism so the voltage had risen; which, he ventured to suggest, demonstrated that the stability of the system left little to be desired. Motor-generators for lighting were no doubt excellent machines, but for traction a good rotary converter was difficult to beat. The floor-space occupied was very small. The rotaries on the Central London Railway stood upon a floor-space 12 feet by 9 feet 6 inches, and there were at Notting Hill Gate sub-station two such machines, with transformers, switch-gear, blowers, and everything else necessary, in a single pit 30 feet in diameter, there being plenty of room. With regard to the Table of costs given by the Authors at p. 53, a rotary converter, capable of carrying 50 per cent. overload for 1 hour and 100 per cent. without serious sparking, could be bought for £3 per kilowatt of rated load (less than £2 per kilowatt of maximum momentary output). Some of the other figures in the same Table should be accepted with reserve, unless it might be taken that the statement in the bottom line of the page covered a multitude of parts. At p. 82 of the Paper a comparison was made between the costs of the Central London and City and South London Railways "per passenger." He hardly thought that such a basis was a sound one, unless it was known that the passengers had actually travelled the same number of miles. For instance, on two lines of equal length, where the average passenger travelled, say, two-thirds of the length of one line and one-third of the length of the other, the train on the former would have to be of greater capacity, and consequently heavier. Such an analogy was probably not a fair one as between the two railways named, because, as the City and South London Railway had both its termini in the suburbs and its more or less central point in the City, it was unlikely that the average distance travelled by its passengers was as long as the

Mr. d'Alton. average on the Central London Railway with its more important terminus in the City, and its less important one at Shepherd's Bush. With regard to alternating-current motors, such as those proposed by Messrs. Ganz and Co. and other continental engineers, the fact that a fixed speed could not be exceeded would, he felt sure, prove a great drawback on any main-line system, or even on a small underground line where a rapid service was maintained. Loss of time by one train from any cause would mean delay to the whole traffic, with consequent decrease in the carrying capacity of the whole line for the day. The Authors gave some hope that the trouble caused by the weakening of the fields in series motors, which was necessary for speeding up, had been solved, and this of course would greatly increase the range of the series-parallel controller, which had the fault that there were only two, or at the most three, notches on which any efficient running could be done. Another point about alternating currents was, as pointed out by the Authors, the increased resistance of the rails; and this seemed to be a more serious factor than was generally supposed. Should a periodicity be used sufficiently high to allow of good lighting off the power-circuit, it seemed likely that the losses would be somewhat troublesome. The results of some tests made on the Central London Railway between the power-house and Notting Hill Gate—a distance of about 1½ mile—showed the apparent resistance of the third rail to be about twenty times as high for alternating current at 25 cycles per second as for continuous current, and that of the running-rails seven times as high; so that on an open road without tunnels something between seven times and twenty times would be expected, such as Mr. Blathy had obtained. The current-density in these tests had been about 35 amperes per square inch. In iron tunnels there was considerably more leakage from the running-rails than there would be on an open road or on a road run through brick tunnels. Of course by the use of two insulated rails of copper, instead of steel, better results could be obtained; but the difficulty at crossings would be serious on a main line, and could not very well be overcome, as shown on the experimental line between Earl's Court and High Street, Kensington, where he believed no crossings or points were, so to speak, "wired in." Bearing in mind the failure of the Heilmann locomotive, scepticism about composite machinery on trains was natural; but he was sure that when the arrangement of Mr. Ward Leonard described by the Authors was put into practice, its working would be watched with keen interest by all engineers. It had been stated that the

overhead trolley system in the Central London Railway depot at Shepherd's Bush had had to be replaced by steam-locomotives for purposes of shunting and yard-work generally. This, however, was not so; the steam-locomotives had been employed from the first for such work, the trolley system being an alternative one. Mr. d'Alton.

Mr. D. Drummond remarked that engineers directly interested in the question must admit there was a clear line dividing the respective suitabilities of steam and electric motive power for application to the working of long- and short-distance traffic; and in no case could electric motive power be produced cheaply so long as steam-power was used to produce the electric current. There could be no question, however, as to the advantage of electrical traction over steam for traffic in large cities, either above or below ground, when worked by light trains running at frequent intervals, and provided with reliable short-distance automatic electric signalling. To attempt to extend electrical traction beyond city limits would only end in failure, and harm would be done to its progress by attempts to extend its use beyond the limit warranted by the existing knowledge of the subject. Main-line traffic, to be economically worked over long distances, must be dealt with by heavy train-loads with the minimum of dislocation by failure of engines or other causes that would tend to delay the working of trains over long distances and for long periods of time. Engine-failures were easily located and seldom happened to be so serious as to prevent the engine from taking the train on to a refuge-siding, causing the least possible inconvenience to the following traffic. A train having its own motive power, subject in every way to the control of the men on the foot-plate, must appeal to the intelligence of engineers as superior to one in which the driver had no control over or knowledge as to the cause or location of failure. As to the important question of the comparative cost of the two systems per train-mile, the cost of electric power for any long distance was still an unknown quantity, and many of the advocates of electrical traction based their comparative calculations on the cost per train-mile as furnished by the half-yearly reports of the railway companies, which was altogether misleading, as there was between 30 per cent. and 40 per cent. of the total engine-mileage which was not shown in such reports, and the expense of which was added to the cost of working per train-mile. Thus, to take the cost per train-mile under these conditions was not only misleading, but gave credit in favour of electrical traction to which the latter was Mr. Drummond.

Mr. Drummond. not entitled. With steam-locomotives which could haul 15 tons of gross load over 1 mile for every pound of coal consumed in the fire-box, and were possessed of many other advantages for the particular work they had to perform, British railway companies were not likely to discard the use of locomotive engines costing £40,000,000 for any other means, until it was proved conclusively that it would pay them to do so. Electrical engineers had a wide field of work in which to gain further experience before they attempted to deal with the larger question of universal electrical traction; and he ventured to say that they had barely reached the border line of economical traction, which must form the essence of the whole question of railway transport.

Mr. Huber. Mr. E. HUBER, of the Maschinenfabrik Oerlikon, remarked that the way in which the Authors arrived at their conclusions was thoroughly scientific; he had not thought that a question so eminently governed by practical considerations was capable of so successful a treatment as it had found at their hands. The firm with which he was associated had arrived at the need for single-phase current by a much cruder method. They had thought it essential to reduce the contact lines to a minimum, and had therefore given the preference to a single line. For the equipment of such a line as the St. Gothard railway, they had desired to keep the currents to be collected from the contact lines within the limits of successful street-railway practice. Nothing would meet these considerations but single-phase alternating current of high voltage. What this voltage ultimately would be, practice must fix. They had found that 10,000 volts was not generally high enough, but that there seemed to be no necessity to go above 15,000 volts; and they took, as an average, at the locomotive, a pressure of 14,000 volts. This would generally keep the current within 50 amperes. There was much available experience of working at this pressure, and it was feasible to wind the motors of the locomotive converter for this pressure directly, without the use of transformers. With regard to the frequency, they had begun with 50 periods per second. At present they were building a locomotive to be operated with current at 16 periods. This meant increased weight for the converter motor; but the loss of pressure in the rail-return was reduced in the ratio 8 : 3, as compared with the loss for the frequency of 42 periods per second used on the Burgdorf-Thun railway. In this connection the question of the disturbance of telephones and telegraphs was a very important one; experiments now being continued in this direction might, however, possibly allow a

return to the higher frequency. If, for instance, on a double-track road 60 kilometers in length six trains were run, each taking 45 amperes from the line, two of them being 20 kilometers, two 40 kilometers, and two 60 kilometers from the feeding-point, then the loss of pressure on these 60 kilometers of return rail would be about 270 volts at 16 periods. If 60 periods were used, the loss would be about 720 volts. But if the boosting could be carried out efficiently, a large loss of pressure would not be more objectionable than a small one, and then a higher periodicity might be advisable in order to economize weight and cost of the alternating-current transformers and motors. They considered, however, that boosting would only partially do away with the return-rail drop, and to keep the remaining drop as low as possible, 16 to 20 periods per second would be necessary. Undoubtedly this was a matter for which a standard should be fixed as soon as possible.[1] The single-contact line of the single-phase system was the ideal as regarded branching off at junctions and sidings. The use of the simple bow instead of the trolley-wheel, solved the problem satisfactorily. They had moreover introduced a two-pressure system in this way, so that certain portions of a road, especially large stations with complicated points, with sheds, yards and the like, were supplied at a low voltage, say 700 volts to 1,000 volts; the current being collected by bows on the locomotives and conducted to the low-pressure terminals directly. It had been necessary, however, to provide a device for the collection of the high-pressure current, that would not get entangled with the low-pressure line and collector. This they had accomplished by a conducting-rod pivoting, in a plane perpendicular to the direction of travel, about an axis on the locomotive, and pressed by a spring or otherwise against the contact-wire. The latter might therefore be suspended along the side of the track without span- or cross-wires (but might also, at certain places, be suspended above the track), the contact-rods always sliding along the wire, making contact from above, from the side, or from below, according to the circum- Mr. Huber.

[1] Since Mr. Huber made this communication he has informed one of the Authors that investigations on this point which have recently been actively pursued have so far shown that apparatus using weak currents seems to remain unaffected by currents of a frequency above 40 periods per second. The loss of voltage in the rails is in any case very small owing to the small current densities; and the speed of the locomotives being perfectly independent of periodicity, it looks as if the system would be a solution of alternating-current traction with periodicities now in use in the majority of power-distribution installations.—The AUTHORS.

Mr. Huber. stances. By curving the rod convex towards the wire, they made it, with regard to wires suspended above the track, a sort of bow pivoting in the said plane about an axis at one of its ends, and capable of running under branching-off wires exactly as did the ordinary bow. In this way one highly objectionable feature of contact-wires, the hanging of them above the track on span-wires, was done away with for all open sections of road, and was confined to those sections where there were branching-off wires and tracks. At the same time it became possible to have two constructionally independent contact lines, one on each side of the track—one constituting a reserve. There were many points of interest about this line-construction, as, for instance, the passing from a high-pressure to a low-pressure section without interruption in the supply of current to the locomotive, and many other points which were necessary to make the whole scheme workable. He would call attention to the great confidence now placed in the contact-lines of railways. Practically no attention was given to their condition during working. This could not be permitted in responsible main railway working, and the Maschinenfabrik Oerlikon proposed to make sections of possibly 10 kilometers each, where the contact-line current and voltage, the rail-return current, and the rail voltage-drop could be read, and the insulation of the line could at any time be observed. At these points there would also be switches to cut feed- or contact-wire sections in or out, to enable a breakdown to be confined to comparatively short sections, which could be repaired. A system of double insulation, with devices to discover a breakdown in the insulation even from a passing train, had also been designed. It was obvious that neither the English Board-of-Trade regulations, nor even the new and liberal regulations in Switzerland, would at present allow contact-lines of bare copper at 15,000 volts. But all such regulations were bound to give way, if high pressure proved to be necessary for traction purposes. The Maschinenfabrik Oerlikon had offered[1] to the Swiss State Railways the equipment of a line 12½ miles long and the hauling of all scheduled trains on this line, comprising several goods trains daily weighing about 200 tons each. The locomotives with motor-transformers became, as a rule, heavier than was required to give the necessary adhesion. As a rule, locomotives for lower speeds than 20 miles to 30 miles per hour weighed about 10 tons per ton of net tractive effort at the coupling. This

[1] The offer has since been accepted: see p. 197.—The Authors.

might be considered a drawback; but there was not more dead weight than was necessary to make adhesion reliable under all conditions of the permanent way. In countries depending on other countries for their coal, the question of economy was of the first importance. The introduction of electrical traction did not depend upon a matter of 10 tons more or less in a locomotive of 800 HP. In any case the saving on the contact-line in cost of plant and power, the simplicity of the line, the perfect speed-regulation, the absence of machinery running idle, and the close supervision of the locomotive plant by the drivers, weighed so heavily in favour of single-phase current at high voltage, that the question of the weight of the converter-locomotive was relatively unimportant. The Maschinenfabrik Oerlikon had made a study of different types of locomotives. The first type had been a 4-axle bogie-locomotive, the converter being situated at about the centre of the truck. Locomotives of about 1,000-HP. could be built on this plan. A more recent and interesting type was the twin locomotive. In this an 800-HP. locomotive was composed of two 400-HP. locomotives, coupled together with their ends carrying the driver's cab. The governing of the combined locomotive was performed by the same driver, the governing switches and resistances being coupled together mechanically or otherwise. This meant having fewer types of locomotives, and having in each locomotive a certain reserve, the locomotive consisting actually of two duplicate parts. The method of speed-control was a very important feature. It must be admitted that the Ward Leonard method of 1891, pure and simple, met nearly all requirements. But for returning energy, for regulating the turning moment automatically during the starting and so on, it was necessary to improve on it. The operation of braking should be interlinked with the regulating switch to prevent the driver from making wrong movements. A novel feature of these locomotives, consequent on the use of single-phase current, would be, that the converter-motor would be provided with two separate windings, one for the high-pressure and one for the low-pressure current, thus avoiding the carriage of heavy static transformers on the locomotives. The single-phase alternating-current system for traction possessed important features besides the single line and the method of speed-control; though the latter, if based on the Ward Leonard principle, in any case greatly improved the efficiency and the power-consumption diagram. The figures for an 800-HP. to 1,000-HP. four-axle low-speed twin locomotive were— Mr. Huber.

Mr. Huber. OERLIKON SINGLE-PHASE ALTERNATING-CURRENT GOODS TWIN-LOCOMOTIVE.

Normal speed	21 miles (34 kilometers) per hour.
Tractive effort (normal)	6·2 tons (6,300 kilograms).
Diameter of drivers	3 feet 11 inches (1·2 metre).
Number of driving-axles.	4
Driving-wheel base of each carriage .	13 feet 1½ inch (4·0 metres).

Length over the buffers of the whole locomotive, about 42 feet 7 inches (13 metres).

Average normal speed of axle motors, 645 revolutions per minute.

Ratio of gearing about 4½ : 1.

Consumption of current at 16·5 cycles = 870 kilo-volt amperes.

Each of the two non-synchronous single-phase motors 970 revolutions per minute wound for the two pressures and currents, viz.:—

14,000 volts × 31 amperes,
and 700 volts × 620 amperes.

Each of the two continuous-current generators, 345 kilowatts (600 volts × 575 amperes).

Each of the 4-axle motors, 200 B.HP. (600 volts × 287 amperes).

Excitation for two motors, 100 volts × 40 amperes.

Excitation for one generator, 100 volts × 30 amperes.

Each of the two exciting-generators, 100 volts × 70 amperes, driven by non-synchronous single-phase alternating-current motors making 950 revolutions per minute, each consuming 17 amperes at 700 volts.

	Tons.
Weight of each of the two carriages	10·0
2 motors with gears	6·0
1 main-converter	9·5
1 static transformer for exciter-motor, air-compressor, lighting .	0·5
1 exciter-converter	0·6
1 air-pump with motor, 2 high-pressure collectors, 1 low-pressure current-collector, switches, regulating-resistances, instruments and conductors	1·4
Total	28·0

Weight of the complete locomotive 56 tons.

It would be noticed that the motors were geared. They were mounted on frames above the axles, supported on springs independent of the spring-suspensions of the vehicle, and coupled to the frame of the vehicle in a peculiar way. This arrangement brought the motors within easy reach of the driver. Locomotives for high speeds would of course be equipped with motors mounted on the axles without gearing, in one of the well-known manners. These remarks might sufficiently prove that the conclusions arrived at by the Authors were capable of being put into practice, and that a system such as that sketched answered the following further requirements:—(1) The possibility of two different pressures for the trolley current, a high pressure for the long open sections, a low one for large stations, yards and the like:

(2) the possibility of having the contact-line along the side of the track: and (3) the possibility of having, along the two sides of the track, two contact-lines, one being a reserve for the other. It afforded him great satisfaction to find two companions of the competence of the Authors in a radical departure from well-established methods. He could not help expressing his admiration of the clear and logical way in which the Authors arrived at their conclusion with regard to what they very properly called a "comprehensive" system. The application of single-phase current to electrical traction constituted a method which had probably been least expected by the great majority of engineers. He hoped that practical results would before very long give the Authors the satisfaction of knowing that the conclusions they arrived at in what might be called a theoretical way were of practical value. Mr. Huber.

Mr. GISBERT KAPP observed that the modification of the Ward Leonard system which the Authors proposed for the propulsion of trains bore a strong resemblance to the system introduced by Mr. Heilmann some years ago on a French railway, the chief difference being in the prime mover. Mr. Heilmann had used a steam-boiler and engine, whereas the Authors proposed a single-phase asynchronous motor. In so far as weight, and possibly also over-all efficiency, was concerned, the Authors' proposal meant an improvement over the Heilmann arrangement, but it might be doubted whether the improvement went far enough to turn the Heilmann system into a success. The Authors gave no figures by which their proposal could be compared with the usual system of working trains by continuous current supplied through a third rail or trolley-wire; it was possible, however, to make the comparison with the materials at hand. It was known what could be done with the continuous-current system, and the features of the various elements which entered into the combination required by the Authors for the conversion of the alternating into a continuous current were also known. The Authors started with the assumption that the train-motors required at starting a large current at a small electromotive force, and when running at full speed a small current at the full electromotive force; and that therefore the generator need never give the large current and the full voltage at the same time: consequently the capacity of the generator need not be equal to the capacity of all the train-motors combined, but might be smaller. This reasoning was fallacious. There was a time when both the large current and the full electromotive force were required by the train-motors, and the generator must give the corresponding out- Mr. Kapp.

Mr. Kapp. put. It was true that it needed to give it for only a few seconds during the period of starting, and, in so far as the size of a machine was determined by heating, there would be a reduction in size and weight as compared with a machine which was called upon to give the full output continuously. This reduction might be estimated at 40 per cent.; and, making allowance for it, the weight of the generator would not be less than 45 lbs. per kilowatt, while that of the motor would be 56 lbs. per kilowatt. It was hereby assumed that the machines were of large size and were run at the highest speed compatible with mechanical safety, say a circumferential speed of 6,000 feet per minute. A train weighing 160 tons and worked at starting with an acceleration of 2 feet per second per second, required a supply of about 500 kilowatts to its motors in the first half of the accelerating period and 1,000 kilowatts during the second half. The power required began to fall off only after the speed had reached about three-fourths of the maximum. At full speed the train-motors required very little current, and in short runs such as had to be provided for in town railways no current at all, since the rest of the run was performed by coasting. The converting-set would therefore have to be capable of giving an output of 1,000 kilowatts, and would not weigh less than 45 tons. This weight, and the space required for the converting-set, precluded the possibility of carrying it in one of the passenger coaches, and a separate tender would have to be provided for it. The weight of this tender, say, about 15 tons, must be added to the 45 tons of machinery, making in all 60 tons. Since the whole train weighed 160 tons, this left only 100 tons for that part of the train which was available for the accommodation of passengers, a reduction of 37 per cent. as compared with a train which received continuous current from a third rail, or which was driven by three-phase current supplied by two overhead wires and the running-rails. The Authors made a point of the fact that, by the system advocated in the Paper, the loss in the starting rheostats was avoided. This was an advantage, but not so great an advantage as the Authors had assumed. They overestimated the rheostatic losses in the older system. A train weighing 160 tons and making a run of ½ mile between stations in 92 seconds, would take from the working-conductor about 19,000 kilowatt-seconds, and of this total only 20 per cent. at most would be wasted in the starting-resistances. If, then, the Authors could not materially reduce these 3,800 kilowatt-seconds, their system had no advantage over the older system in point of energy required per ton-mile. But even if they could save the whole of

these 3,800 kilowatt-seconds, there would be no improvement over the older system, since the saving of 20 per cent. in energy was not an equivalent for the loss of 37 per cent. in passenger accommodation. To make their system equally efficient with the older system they must save at least 37 per cent. of the energy; and a simple calculation showed that this was impossible. The frictional losses in both machines and the iron-losses in the motor were going on all the time; the excitation of the generator must be provided nearly all the time, and only the copper-losses in the two armatures were materially reduced during the greater part of the run. The sum of all these losses amounted to about 12,000 kilowatt-seconds. From this figure must be deducted the energy returned through electric braking. In a $\frac{1}{2}$-mile run the train would reach a maximum speed of 27 miles per hour, and at the end of the coasting period its speed would be 21 miles per hour. The energy then stored in the train was 7,000 kilowatt-seconds, of which amount about 60 per cent. could be recovered. Deducting the 4,200 kilowatt-seconds from the 12,000 kilowatt-seconds loss in conversion, the net loss remaining was 7,800 kilowatt-seconds, or more than twice as much as the rheostatic loss in the older system. In the latter 1 ton-mile, under the conditions stated, would require a supply of energy amounting to 67 watt-hours, while for the Authors' system the figure was 86 watt-hours. It should be remembered, however, that the number of watt-hours required per ton-mile was not the only criterion by which the efficiency of a system must be judged. The proper criterion was the number of watt-hours required per passenger: and judged by this standard, the Authors' system fell hopelessly short of the older system, since it required about double the energy. The difference would not have been so large had the Authors abandoned the use of continuous current altogether and adopted three-phase motors for driving the train. A three-phase motor supplied with single-phase current at two of its terminals would, when running synchronously, give off three-phase current from these two and the third terminal; it would, in fact, act as a converter of single-phase to three-phase current, and, since the conversion took place in the same machine, its weight and the space required for it would be considerably less than with the Authors' converting-set, which consisted of two distinct machines. The weight of a 1,000-kilowatt converting-set would be about 25 tons, and as three-phase motors were a little lighter than continuous-current motors, about 5 tons to 8 tons might be saved in the train-motors themselves. A separate tender would probably not be required for

Mr. Kapp.

Mr. Kapp. carrying the 25 tons of converting machinery, so that 20 tons was the total additional weight to be taken into consideration, leaving 140 tons for the rest of the train. The losses would also be reduced, and it was difficult to see why the Authors had gone only half way towards the use of alternating current. Had they gone the full way by suggesting the system here sketched, their suggestion would not have fallen so hopelessly short of the older system, although it was doubtful whether it would have been an improvement on it. He was inclined to think that it would not be an improvement on the ordinary three-phase system. The only advantage it had was that one overhead wire was saved, and against this must be set the necessity of carrying a converting-set on the train, the loss in conversion, and the reduction in the passenger capacity. It must also be remembered that the single overhead wire must contain more copper than the two wires together in the three-phase system. In his opinion, the Authors had exaggerated the difficulties of a double trolley-wire; and they had hardly laid sufficient stress on the very objectionable nature of a third rail on a level with the running-rails. They objected to the third rail mainly on the grounds of expense on long lines and complication in the shunting-yards. In such places they would not even tolerate the single overhead trolley-wire, but preferred to use a battery locomotive. He could not share their objection to overhead wires, although he quite agreed with them in condemning the live conductor on the ground. The work in a shunting-yard was in itself not free from danger, and if the men during their work were compelled to dodge the live rail, in addition to looking out for moving cars, the number of accidents would certainly increase. It must also be remembered that in some cases it might be necessary to put down a fourth rail for the return current, and the fact of there being two rails side by side, the one dangerous and the other not so, was an additional objection to the system. Much had been made in the recent Metropolitan-District arbitration of the danger of the overhead trolley-wire in case of its breaking. No trouble from this cause had yet been experienced on the three-phase railways on the Continent; but if there should be any doubt on this score it was easy to set it at rest by using for the overhead conductor not a wire but a double T rail, which could be put up as securely as a roof, bridge or any other iron structure. In a shunting-yard or a tunnel or a station it would certainly be advisable to replace the wires by such rails, but on main lines in the open country this would not be necessary. In analyzing the various possible systems, the Authors came to the

conclusion that for transmission alternating current was best, while for driving continuous current was preferable. Their objections against three-phase driving did not seem to be very convincing. The most important was that referring to the necessity of using two overhead wires. Practical experience had shown that there was no insuperable difficulty in this respect. On the Valtellina line two wires were used throughout, not only on the main line but also in the yard. The objection that the speed could not be increased beyond the limit corresponding to synchronism was not justified; for this property of driving by three-phase current was rather an advantage than otherwise. With continuous current a careless driver, on a falling gradient, might allow the speed to rise to a dangerous amount, as had been shown some years ago by the accident at Fiesole, near Florence. This was impossible with three-phase driving. If provision was made for working the motors in concatenation, the train could travel at either half speed or full speed without rheostatic loss. With continuous current, rheostatic loss did not take place at half speed, and at from three-quarter to full speed only by alternately accelerating and coasting; that was, continually varying the speed between narrow limits. This threw more work on the driver, so that the alternating system was, if anything, preferable as regarded constancy of speed. Another objection raised by the Authors was that referring to waste of energy. The measurements which he had made on the Valtellina line with runs of 1 mile had shown that the input of energy was about the same as would be expected with continuous current. At starting the rheostatic loss was a little larger, but the difference was made up by the energy returned when braking by concatenation. Mr. Kapp.

Mr. O. LASCHE, of Berlin, remarked that the views of the Authors were set forth with such clearness and ability in the Paper, and so thoroughly supported by facts, that it seemed to be scarcely possible to deal more fully with individual points. He would, however, venture to add a few words upon the question of high-speed railways. The generating-station for the high-speed railway near Berlin was at Oberspree, about 9·3 miles distant from the track conductor. The current was generated at 6,000 volts, transformed up to 12,000 volts, and supplied at this potential to the overhead wire. This potential of 12,000 volts was sufficient for transmission of the current, as the distances in question were short. As pointed out by the Authors much higher potentials had already been employed for long-distance transmission-lines. It seemed exceptionally risky, however, to wind railway motors for this potential of Mr. Lasche.

Mr. Lasche. 10,000 volts to 12,000 volts, as it was naturally far simpler to maintain a transformer in proper condition for a number of years, even if such a transformer were merely insulated with air. With this consideration in view, transformers had been built into the car, and had naturally added greatly to its weight. In future projects, therefore, under similar circumstances, a potential of 2,000 to 3,000 volts would be adopted for the overhead conductor, as for these potentials it was possible to construct motors which would have a satisfactory life. The overhead conductor consisted of three wires, arranged in a vertical plane above the side of the car, and at a distance of 1 metre apart. Such an arrangement was, of course, only possible when the line was not crossed by other lines, by bridges or by tunnels. In cases of that kind the conductors must be placed differently, in order to avoid the disadvantage of being obliged to include the lofty double or treble conductor in the clear height required above rail-level. With reference to the periodicity, it might be said that frequencies varying between 25 and 50 periods per second had been used, and it had been found that the motors developed the same torque so long as the ratio between frequency and potential remained constant. Tests had been made with these changes of frequency, and, moreover, observations had been taken when travelling at low speed, while using the highest frequency; and it had been proved that the liquid starting-resistance behaved well, and also acted satisfactorily with the rise of energy at starting, and with the reverse current developed when the brake was put into action. Braking by means of the reverse current had given no appearance of trouble, in spite of the important rise in potential in the armature-windings and starter. The continuous-current brake had not as yet been tested upon the line, because naturally continuous-current braking was most efficient at the highest speed, while at low speeds the air-pressure brake was assisted but little by the electrical brake. As to the running tests, he might add that hitherto these had been merely of the nature of preliminary and tentative trials, as nothing more had been possible; but the work would be continued in the summer of 1902.

Mr. Shoolbred. Mr. J. N. Shoolbred considered that the Paper was not only highly interesting and lucid in treatment, but was extremely opportune at the present time, when, in connection with electrical propulsion, a network of communication throughout a large part of Great Britain was being contemplated for passengers, goods and minerals, on a scale which had never before been attempted. The essential feature of such a network, if the fullest

benefits of convenience and economy were to be the results to the community at large, must be uniformity throughout, and interchangeability of the various parts. That was to say, there must be uniformity in the gauge of the vehicles and in the electrical pressure employed. As a first step, it must be realized generally that, as the Authors remarked, there was no natural distinction between electric railways and electric tramways; a statement which applied not merely to technical arrangements, but also to the material interests of both the railway and the tramway. The Board of Trade, however, appeared to think otherwise. Judging from their recent instructions to the Light Railway Commissioners, they seemed to consider that active hostility between railway and tramway must exist. Nor did they appear to realize that each could be of advantage to the other. As a contrast to this, he might mention a recent expression of opinion by the general manager of one of the leading railway companies in England, who had remarked to him that he considered competition between railways and electric tramways was the coming question, and it must be faced—but in a friendly spirit, to their mutual advantage, and not in dogged hostility. If this general inter-communication in the modes of transport by electricity was to be effected, uniformity of gauge was the most essential point. The railways having all adopted the 4-foot 8½-inch gauge, it was imperative that the electric tramways should adopt the same gauge, despite the narrowness at certain points of streets and highways. The variety of the different gauges which were in use—some differing but little from others—seemed incomprehensible. The action of certain County Councils in memorializing the Board of Trade in favour of the 4-foot 8½-inch gauge, and also themselves strongly opposing any other, was exercising a beneficial effect towards arriving at the uniformity which was so desirable. The next most material point was uniformity in the electric working-pressure. The action of the Board of Trade in fixing 500 volts as the maximum working-pressure for both electric railways and electric tramways, and in adhering to the same limit in the recent arbitration as to the electrification of the metropolitan underground lines, had done much towards ensuring uniformity in this direction. As regarded the actual system of generation of the electric current, it was the simplicity and safety attending its working-arrangements that must cause the continuous current to prevail over the alternating, as had been the case in many large electric-lighting generating-stations, especially in the Metropolis. Again, the devices adopted by Mr. McMahon on the City and Mr. Shoolbred.

Mr. Shoolbred. South London Railway for the extended use of continuous current over longer distances, were not only very ingenious, but they gave ground also for the hope, which he trusted would soon be realized, that other devices might follow, by which continuous current could be used over long distances such as occurred on main lines.

Mr. Thrupp. Mr. Edgar C. Thrupp remarked that at p. 51 the Authors, in referring to the City and South London system, observed that it was quite possible that system would be found more economical, both in first cost and in working-expenses, than the Central London system. That was a remarkable admission; and if, as he understood was the case, the efficiency of the Central London system was somewhat overstated in the Paper, it would be emphasized thereby. It was not clear from *Fig. 2* whether the "reducers" at London Bridge and at Islington were worked independently on each side of the middle wire, or were coupled so as to form one machine with four armatures on a single shaft. There would appear to be no reason why the two sides should not be so coupled, while, on the other hand, there would be a distinct advantage in making them act as perfect "balancers," and thus dispensing entirely with the separate balancers. No reason had been given by the Authors for dismissing this system as unsuitable for long lines. If it was to be assumed as an axiom that a line, however long, must be worked by one generating-station, of course the Authors were right in dismissing the system; but the policy of adopting one generating-station was by no means beyond question. The usual argument in favour of high-tension current was that it saved copper; but if its adoption also involved longer feeders that argument lost much of its force. For instance, a line 100 miles long, served by one generating-station, would have feeders averaging 25 miles in length; while the same line, worked by ten generating-stations placed 10 miles apart, would have feeders averaging 2½ miles in length. To show any saving in copper in the feeders in the first system the pressure must be more than ten times as high as in the second system, or over 20,000 volts, to compare with 2,000 volts in the latter case. Another argument in favour of the use of a single generating-station was that it saved skilled attendance at numerous points; but the cost of such attendance in connection with works of the magnitude required on main lines was really a mere trifle, and could not be expressed in pence per unit without using three places of decimals. A main line would require upwards of 5,000 HP. on every 10 miles of its length, if the traffic was of such a character as to justify the

introduction of electrical traction at all, and the power was more likely to be 10,000 HP. Could it be contended that stations of these outputs were not workable economically? A new argument had now appeared in favour of extra-high pressure, namely, that it rendered the collection of the current on a trolley-wire more easy. In connection with this argument it was also contended that such pressures on overhead wires were after all not so very dangerous. This point would require serious consideration, and it was unwise to lay down the law either for or against it; but was it necessary to use high pressures for such reasons? If the current was too large to be picked up at one point, it could easily be picked up at several points, so as to reduce the volume at one contact. If it was conceded that a pressure of 2,000 or 3,000 volts was admissible on trolley-wires, then it must follow that a continuous-current three-wire system, using 2,000 volts on each side, was also reasonable. The introduction of electrical traction on main lines was generally admitted to be somewhat remote, but it was suggested that its consideration now might prevent the adoption on short lines of systems which were unsuitable for long lines, and the point was a sound one. Had it occurred to the Authors that in the course of the years which would elapse before the main lines were electrified, the use of very large gas-engines would become one of the most important accomplished facts in connection with large power-schemes in Great Britain? The types of large gas-engines which had recently been so successful on the Continent were not suited to driving alternators, but they were suited to drive continuous-current dynamos. Possibly improvements might be made which would alter this state of affairs; but it would be a deplorable mistake to adopt on railways generally an electrical system which, from its very nature, would prove a bar to the introduction of gas-power, and a consequent saving of 50 per cent. or more in the fuel-bill. Mr. Thrupp

Mr. B. H. Thwaite remarked that the Authors might be congratulated on having done a timely service by their analysis of the present position of electrical traction applied to railways. He considered, however, that as far back as 5 years ago, the evidence of success then obtained had been sufficient to justify British railway companies in at least tentatively adopting the system. Unfortunately for the future prosperity of the country, the same arguments were used by the railway companies that were often employed by many British manufacturers in their objection to the employment of more economical and efficient processes and appar- Mr. Thwaite.

Mr. Thwaite. atus; namely, that the adoption of such improved apparatus and processes would destroy much of the value of their existing plant. But if it could be shown that a new system would secure such sterling economies as to provide a sinking-fund to permit the wiping out of existing and inefficient rolling stock or other plant in a certain number of years, in addition to securing increased profits, it was surely true economy to adopt such a system. Further, it might justly be asked whether the country was to be allowed to fall away in its manufacturing efficiency compared with other countries, because the railway companies, with their Parliament-granted monopolies, refused to move along lines of progress. Too much honour could not be given to those responsible for the adoption of electrical traction on the Liverpool Overhead Railway. Nine years had elapsed since the date of the running of the first electric train on that line, and considering that the application had been in the nature of a pioneer one, its success had magnificently justified the courage of those responsible for the selection of electric instead of steam power. Of course the electrical transformation of the railway systems would be a work of very considerable magnitude and difficulty; but British engineers had infinite resources, and besides, the race that had produced Stephenson and Faraday should really have been the first to apply the electrical system to railways. In an article[1] on "The Influence of Electricity upon Railway Locomotion," he had pointed out that existing steam-locomotives could be brought into service for siding- or shunting-work, the initial electrification being confined to the trunk lines; further, the electrification of the lines could be proceeded with without seriously interfering with the running of the steam-locomotives. The article in question gave *inter alia* the comparative fuel-cost of steam and electrical traction, the economic advantages in favour of the latter equalling 103 per cent. The comparative total running-cost per ton-mile gave the electrical system an advantage of about 37 per cent. But even this comparison did not cover all the advantages of electrical traction. The coal-consumption of the Liverpool Overhead Railway (the example chosen for the comparison) could be reduced by 50 per cent.; in fact, there was no reason why, making ample allowance for absorption of energy in mechanical and electrical transformations, an actual and sustained thermodynamic efficiency of 17 per cent. should not be obtained at the axles of the electric train, compared with, say, 4 per cent., which was probably the

[1] *Engineering Magazine*, vol. xvii. p. 415.

highest obtainable everyday efficiency on the best locomotive. Mr. Thwaite. There were other all-important advantages, in the reduced wear and tear of rolling stock and permanent way, and especially the reduced depreciation of tunnels and iron bridge- and station-structures; and the electrical power would also be available for service in warehouses and on canals owned by railway companies. These advantages alone, in their accumulated measure, would provide a sinking-fund that would in a reasonable period extinguish the cost involved in the coming and inevitable displacement of the steam-locomotive. Further, railway directors, as part of the electrification programme, could adopt the American bogie goods-wagon, having a capacity of 20 tons to 50 tons, and could equip such wagons with their own electric motors. The increased profits that would result from the large reduction in working-expenses (outside the economic policy of low freight charges which he had demonstrated statistically in a lecture[1] delivered before the London Chamber of Commerce) would enable the companies to make a considerable reduction in British railway freights, which now constituted a handicap that placed the British manufacturer at a serious disadvantage compared with his American and German competitors; for instance, the goods rates for heavy raw materials were 300 per cent. to 600 per cent. higher on British railways than on the more progressive of the American railways. In the article in the *Engineering Magazine* referred to, he had suggested that the ideal method of transportation overland of heavy manufactured and raw materials and products, between industrial and inland centres and a port, or even across England—Carlisle Port to Newcastle, for example — would be by the use of electrically-equipped bogie goods-wagons of at least 20 tons net capacity. The possibility of utilizing the electric energy generated on the down gradients, by the employment of alternating-current motors, would enable electric lines over undulating country to be constructed at a minimum of cost in tunnelling, viaduct, or embankment work; and for a cross-country goods line, such as that proposed, there would be little difficulty in organizing the train service so that the returned energy due to falling gradients could be fully utilized. Railways like the Taff Vale line, South Wales, were well adapted to such an application. Besides, the main generating-station could be located at the coal-pit. The Authors' description of the working of the

[1] "On Home and Foreign Railway Rates for Goods Traffic." *The Times*, 10th Mar., 1899.

Mr. Thwaite. Engelberg electric railway constituted a remarkable illustration of the wonderful elasticity and resources possessed by electric power. No doubt it would be realized that for main-line service with corridor-coaches and goods wagons of large capacity, distributed electric motors would be found the best, both for dynamic and for static or structural reasons; and with self-propelled units there would be no difficulty at level crossings, where the conductor could be placed below the surface of the ground. But for branch railways, probably an electric locomotive would be found to be the most serviceable. The moment had arrived when the British Government should be asked to appoint a commission of railway and electrical experts to decide finally upon the best system to be adopted, otherwise the costly experience of the early railway days would be repeated, in which the use of two distinct gauges, the broad and the narrow, had been permitted, a liberty that had involved the Great Western Railway in immense losses. If in the first instance the electrification of the railways was limited to the main lines, employing steam-locomotives for shunting, the railway companies should have no hesitation, under the guidance of the Board of Trade, in commencing seriously the desirable work of electrification; and probably the Great Central Railway would offer the least initial difficulty in effecting such a transformation. Even if the system in use on the Liverpool Overhead Railway was adopted—but with power-gas plants driving three-phase generators, the stations being located along the line at intervals of 50 miles, to supply energy to intermediate distributing-stations for feeding the train-motors with suitable current—such an application would really leave little margin for further economic improvement. It was sincerely to be hoped that the "battle of the gauges" of the forties would not have its counterpart in a battle of phases, pressures and currents; such a struggle could only retard seriously the urgently desired electrification of the railways. In the article in the *Engineering Magazine* already referred to, he had proposed the use of power-gas generating-stations, the gas-engines being so arranged as to be rapidly responsive to variable demands for power, without the necessity of accumulators. The arrangement consisted in a modification of the plan described in a Paper [1] read

[1] "Economic Possibilities of the Generation of Electro-motive Force in the Coal Fields, and its Application to Industrial Centres," by B. H. Thwaite. Transactions, Manchester Association of Engineers, 1892, p. 197. Partly written in collaboration with Mr. James Swinburne, M. Inst. C.E.

by him at Manchester in 1892. The full-power output was furnished by a number of suitable units which, when doing effective or external work, were always working at three-quarter to full power. The other engines were also kept in motion (without compression effect) at one quarter of full-power speed, being driven electrically from the main electric generators. When the load was increased, the gas-valves and the exhaust-valves of the gas-engines were, by electrical means, automatically opened or set free, and the full effective output to meet the demand was rapidly obtained. On the falling-off of the load, the valves were again electrically and automatically actuated, shutting off the gas, and the motion of the corresponding engines was again sustained by electric power; thus the output would rapidly respond to the demand, and the power-output of the gas-engines would be kept up to that corresponding to the maintenance of the highest thermodynamic efficiency and the most satisfactory cyclical regularity. He would also suggest that, as many of the British railway companies derived a considerable portion of their goods receipts from ironworks served from the main lines, and generally situated only a short distance from them (the Midland Railway Company being particularly well favoured in this respect, at least in the length between London and Leeds), the electric energy required might be generated from the waste gases of the blast-furnaces. He was already obtaining power from these waste gases evolved from two of the ironworks on the Midland Railway, the constant thermodynamic efficiency being about 25 per cent. The blast-furnaces in close proximity to the Midland main line could be relied on to provide the major part of the power required on the line from Leeds to London; and by the system described in his Paper[1] read before the Iron and Steel Institute in 1901, this power could be continually produced whether the furnaces were in constant service or not. By utilizing this blast-furnace power the railway companies would benefit one of their best customers and obtain power at a very economical figure. An important feature of electrical compared with steam traction, and one that had hitherto not been sufficiently emphasized, was that locomotives were delayed many times a day in sidings and elsewhere, and their energy was unavailable for service on other parts of the line; whereas this energy, in a central generating-station, might be diverted to another train. Therefore, with the electrical system, less than 75 per cent. of the aggregate power of the necessary steam-locomotives would suffice Mr. Thwaite.

[1] Journal of the Iron and Steel Institute, vol. lx. p. 149.

Mr. Thwaite. for the service. Further, the generating-machinery, being placed under cover, would be preserved in the highest state of efficiency, whereas the locomotive generator was placed, when working, under the worst conditions to secure high efficiency.

The Authors. The AUTHORS remarked that they found it impossible to reply in any reasonable space to all the points raised in the large amount of valuable matter contained in the Correspondence. They hoped that the forthcoming trials on the Swiss State Railways might settle many of these points, and provide a better basis than theory or argument for the formation of opinions. Referring to some of the criticisms, they had never stated nor supposed—as seemed to be thought by Mr. Behr and others—that electrical traction was likely to be introduced on main lines for the purpose of immediately or completely superseding steam. When once introduced for a small portion of the traffic, electricity, if successful, would no doubt gradually increase its usefulness; but even under conditions most favourable to electricity it was fairly certain that steam would remain. The important point was not to begin on wrong methods. The change must be gradual, and it was on this account absolutely essential that the system adopted for the first small part should be capable of extension to longer lines and a greater traffic. The objections raised by Mr. Behr in the first part of his communication were answered in the second part. The Authors quite agreed that, for helping to deal with exceptionally heavy occasional demands, steam would be a useful and important auxiliary to electricity, even on lines where the bulk of the work might be done by electricity. It was not a question as between steam and electricity—neither excluded the other. For an infrequent service, especially on long lines, the steam-locomotive must continue to have great advantages. Under such conditions it might some day be hard pressed by some other heat-motor, it was never likely to be superseded by electricity. For long lines with small traffic the Authors were entirely in accord with Mr. Horace Bell's criticism, in the Discussion, of Colonel Crompton's proposals for the working of the suggested Himalayan line. No water-power, however cheap, could enable electricity to compete with steam under such conditions. With regard to Mr. Drummond's suggestion that in an electrically-driven train the driver had no control over, or knowledge as to, the cause or location of failure, there was no reason why the driver should not understand the machinery under his control. The fact that it was much simpler and could all be inspected and overhauled at a moment's notice by

switching off the current, made repairing a simple matter compared with repairing an engine with its fire and boiler, and everything hot. Again, it was possible to duplicate the driving machinery, allowing one set to be entirely cut out should it fail, leaving sufficient to take the train on. In comparing steam and electrical haulage, such points should be borne in mind as the collection of water by the moving train, the difficulty of lubricating the reciprocating parts and slide-bars for the long runs now made, the great weight and bulk of coal to be carried, the maintenance of the water-level and the steam-pressure—all essential matters in a steam-locomotive. On comparing such difficulties with the absolute simplicity of the rotating electric plant which could all be enclosed, with a few bearings only to lubricate, and nothing to do but turn a handle in order to go faster or slower, it could be realized what an immense difference there was in favour of electricity. Mr. Kapp had made an interesting suggestion for applying the method of Ferraris and Arno [1] to the construction of the travelling motor-generator, converting from single-phase to three-phase in one machine, using three-phase motors instead of continuous-current motors on the train, thus having alternating current throughout. It was quite true, as Mr. Kapp pointed out, that this method would simplify and lighten the motor-generator, but—so far as the Authors understood it—it would do so only at the sacrifice of the main feature of the Ward Leonard system, namely, the independent variable excitation of the generator which gave the variable-ratio effect and the absence of resistance-losses in the Ward Leonard method. It did not seem that the Ferraris-Arno plan could give any equivalent of this, except at the cost of variations of the power-factor so great as to more than counterbalance the gain in weight. In fact, this plan would not improve matters on the locomotive, and might cause serious difficulties on other parts of the system. Mr. Kapp had misunderstood the Authors as to the methods of working shunting-yards, as they would certainly, where possible, keep the conductor overhead, using a bow collector to avoid difficulty at points. After writing the Paper the Authors had learned from Mr. E. Huber, Managing Director of the Maschinenfabrik Oerlikon, that that Company had independently arrived at conclusions similar to their own as to the possibilities contained in a single-phase system combined with a travelling motor-generator. Since then they had been informed by Mr. Huber that the Board of the Swiss State The Authors.

[1] Minutes of Proceedings Inst. C.E., vol. cxxvii. p. 484.

The Authors. Railways had formally accepted an offer made by the Oerlikon Company to apply this single-phase system. The trial line was the Seebach-Wettingen line of the late Nordostbahn, now the Schweizerische-Bundes-Bahn, and was about 12½ miles long. The Authors were very glad to see Mr. Huber's communication, giving such full particulars of the plant to be used for this purpose, and stating his views on a number of points raised in their Paper. It was clear from Mr. Huber's remarks that his firm had gone very fully into all the details. The Authors welcomed also the confirmation of their views contained in the communication from Mr. C. E. L. Brown, who, as was well known, was responsible for the important three-phase applications on the Burgdorf-Thun line of the Swiss State Railways and on the Stansstad-Engelberg Railway. Mr. Brown, whose experience of alternating-current railway traction was unequalled, now recognized that the weight of the locomotive, which he had formerly thought would be the main drawback, was much less than he had supposed, because the motor-generator, being run at a high speed, could be comparatively light, as indeed was pointed out by the Authors. Mr. Lasche, who had had special experience on the three-phase, high-speed line at Zossen, also appeared to agree with their views: his remarks confirmed the objections to three aerial lines, and supported the view that there was no need to use frequencies so low as to be unsuitable for lighting purposes. On this point Mr. Huber's experiments seemed to lead to a similar conclusion. The question of frequency had been raised several times, and it was hoped that before long it might be possible to settle it in such a way that there would be no need for conversion from alternating- to continuous-current for lighting purposes. It was interesting to note that Mr. Huber advised the adoption of 15,000 volts on the line, and proposed to wind the motors of the motor-generator for this pressure; whereas Mr. Lasche considered 3,000 volts high enough for the motors if used for driving the train direct. If both conclusions were right they formed a strong argument in favour of the use of a high-tension motor-generator, and low-tension motors on the car-axles. It might be pointed out that during recent years in America the tendency seemed to have been to abandon the very low frequencies which had been at one time supposed by many engineers to be necessary for large transmission schemes. In many of the later schemes frequencies of from 40 periods to 60 periods per second were in use. This gave the advantage of direct application to all classes of work without any rotating transformers. Almost the only practical advantage of

low frequencies was now admitted to be the greater facilities they afforded for the use of rotary transformers; but, as pointed out in the Paper, rotary transformers had little advantage in cost and efficiency over motor-generators, and, as compared with the latter, had some serious disadvantages for lighting, such as requiring additional transformers and rendering less easy the independent control of the pressure in the primary and in the secondary lines and of the power-factor of the primary. The communications from the experienced continental engineers mentioned were naturally of great interest to the Authors, who were glad to be able to say that the soundness or otherwise of their views would soon be put to a practical test—a circumstance which they had not expected for some years. Their object would have been attained if it was recognized that it was highly advisable to begin to use electrical traction on main-line railways on some plan which had in it the essentials which could lead to success on long lines by a gradual and natural growth of the original system. However well adapted a method might be for short lines it did not seem wise to apply it, even on short portions of long lines, unless it contained those essentials. The Authors.

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25 February, 1902.

CHARLES HAWKSLEY, President,
in the Chair.

The discussion upon the Paper, "Electrical Traction on Railways," by Messrs. Mordey and Jenkin, occupied the evening.

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4 March, 1902.

CHARLES HAWKSLEY, President, in the Chair.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

Members.

Harold Thomas Ashton, D.Sc. (*Victoria.*)
Herbert Jefcoate Atkinson, B.A.I. (*Dubl.*)
James Benjamin Ball.
Leonard Moore Bell.
Robert Brodie.
Francis Dundas Couchman.
Lloyd Hassell.
Harry Herbert Jones.
Ernest Edward Light.
Richard William Frederick Longfield.
Robert Jarratt Money.
Harry Ernest Prescott, M.A. (*Cantab.*)
Henry Ashman Read.
Frederic Shelford, B.Sc. (*Lond.*)
Ernest Talbot.
Robert John Thomas.

And that the following Candidates had been admitted as

Students.

Sydney Hembrey Dean.
Edward McCarthy Fitt.
Andrew McClure, B.A. (*Oxon.*)
Edward Percy Wooldridge.

The Candidates balloted for and duly elected were: as

Members.

Bernard George Arkwright.
Albert Neumann Connett.
Hugh Hannay McClure.
James Robert Twentyman.

Associate Members.

William Richard Thomas Cottrell.
John Duncan Campbell Couper, M.A. (*Cantab.*), Stud. Inst. C.E.
Arthur Dixon, Stud. Inst. C.E.
Edgar James Edwards.
Oscar Harfeld.
Henry Angley Lewis-Dale, Stud. Inst. C.E.
Ralph Oakden, Jun., Stud. Inst. C.E.
Frank James Oerton.
Frank Sharman Rishworth, B.E. (*Royal*), Stud. Inst. C.E.
Harold Jacob Saunders, Stud. Inst. C.E.
Russell Scott Scholefield.
Andrew Hepburn Whitelaw, B.Sc. (*Glas.*)

The discussion upon the Paper, "Electrical Traction on Railways," by Messrs. Mordey and Jenkin, occupied the evening.

11 and 18 March, 1902.

CHARLES HAWKSLEY, President, in the Chair.

The discussion on Messrs. Mordey and Jenkin's Paper occupied these evenings.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 3310.*)

"The Erection of the Walnut-Tree Viaduct, on the Rhymney Branch of the Barry Railway."

By ALFRED PEARCE, M. Inst. C.E.

IN the following Paper the Author describes the construction of the Walnut-Tree Viaduct, of seven spans, which carries the Rhymney Branch of the Barry Railway across the Valley of the Taff, about 5½ miles north of Cardiff, Fig. 1, Plate 4.

Foundations.—The excavation for the foundations of the piers was commenced on 7 July, 1897, pier No. 2 (Figs. 2, Plate 4) being the first started. Owing to the nature of the soil passed through, which was in every case ballast, with thin layers of running sand, the excavation was carried down the full size of the concrete foundation, with timbering, runners being used in all cases. The running sand gave very little trouble except in pier No. 3 (Figs. 2, Plate 4), where several times the bottom gave way during the night, when work was stopped. This was overcome by working day and night, and keeping the sump well below the bottom of the workings. The River Taff was also a source of trouble, owing to the land on which piers Nos. 3, 4 and 5 stand becoming flooded when heavy rains occurred in the hills above; but by carefully watching the river, and by keeping small dams round the excavations, damage to the timbering was almost entirely prevented. At pier No. 5 a coffer-dam had to be constructed, as the foundations of this pier were partly under the bed of the river. Piers Nos. 3, 4 and 5 were founded on ballast, and Nos. 1, 2 and 6 on compact mountain-limestone rock; the rock being sidelong, and dipping towards the centre of the valley, was stepped to receive the concrete, Figs. 2, Plate 4.

The concrete in the foundations was 8 to 1 cement-concrete throughout, except in the case of pier No. 2, for which 4 to 1 lime-concrete was employed. In every case large stone displacers of pennant-stone, weighing, on an average, about 5 tons each, were

bedded in the concrete. The stones were not placed nearer to one another than 1 foot 6 inches apart, and were dropped on to the green work, in order to thoroughly incorporate them with the concrete. The concrete was brought up to within 5 feet of the surface of the ground, and on it the brickwork of the piers was commenced.

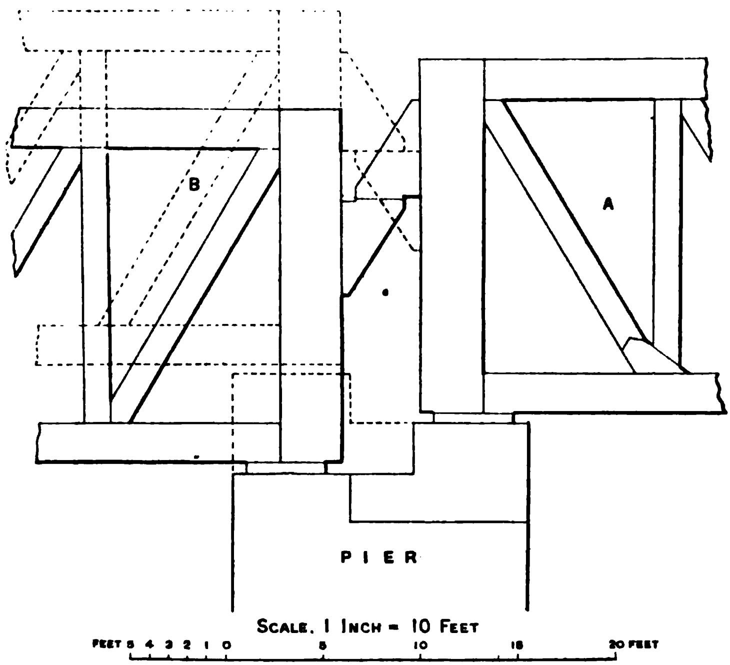
The abutments and wing-walls were all founded on the rock, which had to be carefully stepped to receive the concrete put in to give a fair surface to the brickwork.

Abutments and Piers.—The whole of the abutments and piers are built of bricks, the face being of Catty Brooke brindles, and the inner work of red bricks made in the district. Samples of the bricks to be used were submitted by the contractors to the engineers for approval, as, owing to the methods employed in erecting the superstructure, and in bringing up the piers, the brickwork had at times to withstand a pressure of 20 tons per square foot on work 7 days old. In the design of the piers, in plan (Figs. 3, Plate 4) are shown two pockets, which are taken up to within 11 feet of the girder-beds, and are left hollow in order to lessen the weight on the foundations as much as possible, this in no case being more than 4 tons per square foot. Screens of brickwork have been erected on each pier, to hide the ends of the girders and to form a feature to the work, Figs. 2, Plate 4. The brickwork is built in 2 to 1 cement-mortar, with the exception of that of the pilasters of the piers on which the girders rest, and which had to support the girders during erection, this being built in 1½ to 1 cement-mortar, in order to set more quickly, and thus hasten the progress of the work.

Superstructure and Method of Erection.—The method of erecting the ironwork, and the manner in which the piers were built up, are illustrated in Figs. 2, Plate 4, and in *Fig. 4.* The main girders, cross girders and decking of span No. 4 were built and completely riveted up on a low trestle; the whole span was then lifted by means of four hydraulic jacks placed under brackets attached to the ends of the girders, timber was inserted in place of the jacks, and the brickwork was built up under the girder, which was not allowed to rest on the new work until it had set. This was continued until the level of span No. 3 was reached, when this span was brought up in the same way and at the same time as span No. 4, the girders being hung on one another alternately, during the process of lifting, by means of reversed brackets, and half the pier being built up to the new level at each lift, as shown in *Fig. 4.* When the girder A had been lowered on to the new work, girder B was lifted and hung on girder A, the process being

repeated at each lift. After several trials, 5-foot lifts were found to be most suitable; the stroke of the ram being only 1 foot 5 inches, 1-foot timber packings were slipped under the girders at each lift, and a packing-piece, circular in plan and 1 foot in depth, was put on the top of the jack, so that, at the last lift of 1 foot, the ram and packing-pieces formed a column of about 7 feet 6 inches in height, and it was found inadvisable to make this column higher, having regard to the weight of the

Fig. 4.



METHOD OF ERECTING GIRDERS AND BUILDING PIERS.

girders. The ends of each span were lifted alternately, so that the span itself was never more than 6 inches out of level in its whole length. A different method of erection was adopted in the case of spans Nos. 6 and 7. As the viaduct crossed the Taff Vale Railway at this point, the erection of these spans on trestles would have involved considerable expense, and it was therefore arranged to launch them from the northern abutment. To facilitate the work of erection, a strong trestle was built close to this abutment; the north end of span No. 7 and the main girders, cross-

girders and decking of the south end of span No. 6 were then riveted together on this trestle, and when ready were launched forward, more steelwork being then added. When span No. 6 was finally riveted together, the south end of span No. 7 was bolted to it temporarily, and the work was launched forward until the two spans were in their proper positions. They were then lifted, in the manner already described, until the correct level was reached. Owing to the manner of launching spans Nos. 6 and 7, the stresses in some of the members of the girders were reversed; the tension-members were therefore strengthened by having a baulk of timber inserted between the tie-rods and firmly bolted to them. The bottom boom of the girder was stiffened by having an extra angle-bar put on. The girders were pulled out, in launching, by means of a steam-winch and pulley-tackle; the girders themselves rested on rollers, and temporary plates were fixed on the underside of the bottom flange to cover the rivet-heads. The whole erection was done without a hitch, and great credit is due to Messrs. Head, Wrightson and Company for carrying it out so successfully. The general design of the girders is shown in Figs. 5 and 6, Plate 5. Owing to the heavy nature of the Barry Railway Company's engines, the cross-girders would be called upon at times to take a weight of 80 tons. They had therefore to be of special design, Figs. 7, Plate 5. The viaduct, as shown in Fig. 1, Plate 4, is on a curve at the two ends, with a straight portion between. The distance laterally between the girders on the straight portion is 24 feet, and on the curve, which is of 1,000 feet radius, it is 27 feet 3 inches, to allow for the curvature of the line.

The engineers for the work were Sir John Wolfe Barry, Past-President Inst. C.E., and Mr. C. A. Brereton, M. Inst. C.E.; the contractors were Messrs. Price and Wills and the sub-contractors for the ironwork and erection were Messrs. Head, Wrightson and Company, Limited, of Thornaby-on-Tees.

The Author acted as Resident Engineer for Sir John Wolfe Barry.

The Paper is accompanied by five drawings, from which Plates 4 and 5 and the Figure in the text have been prepared, and by twelve photographs.

(*Paper No. 3320.*)

"Sea-Wall at Woolston, Southampton."

By Francis Webb Wentworth-Sheilds, M. Inst. C.E.

In carrying out the sewerage of the Itchen Urban District, Southampton, the Author had to prepare a site for purification-works by reclaiming part of the eastern foreshore of Southampton Water at Woolston, opposite the south end of the Southampton Docks. This work involved a sea face-wall of concrete, 16 feet in height from top to base, with reclamation filling behind it; the construction of the sea-wall is described in the following Paper.

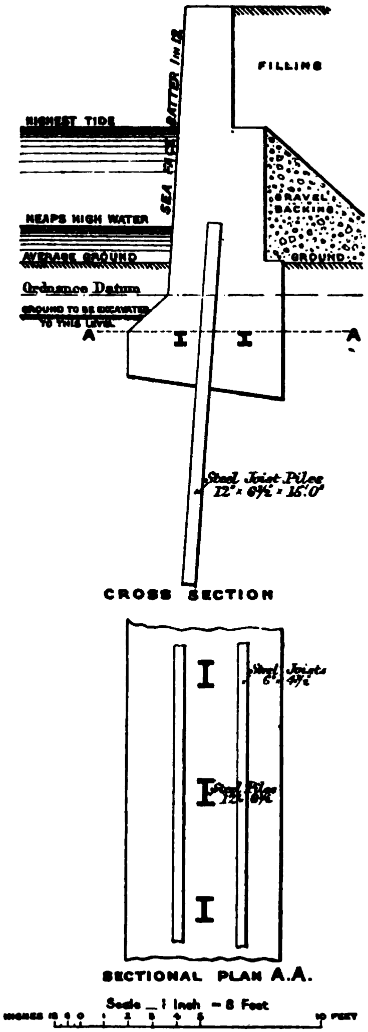
The ground-line is about 6 feet below high-water level and is dry at half-tide. The soil consists of a wet alluvial deposit of clay and sand, and the experience obtained by other engineers, in constructing the Southampton Docks retaining-walls on the opposite shore, proved that the main precaution requisite was to lay the foundation of the sea-wall in such a manner that the wall should not be forced forward by the pressure of the filling behind it. The usual construction in such cases is either to lay the foundations at a great depth, or to sink cylinders or drive close piling finishing at ground-level in front of the wall, or to tie back the wall by iron rods, to piling at some distance in the rear. The Author considers, however, that the construction which has been adopted possesses advantages over either of these methods.

Steel joists, 12 inches by 6½ inches, by 15 feet in length (weighing 64 lbs. to the foot), were driven as piles 5 feet apart, centre to centre, along the centre-line of the space occupied by the wall-foundation, and to a depth of 13 feet below ground-level, or 8 feet 6 inches below the wall foundation-level, *Figs. 1.* Above foundation-level the pile-head was embedded in the concrete wall. As an additional precaution against unequal settlement, two horizontal rows of steel joists, 6 inches by 4½ inches in cross-section, in lengths of about 35 feet, were also embedded in the concrete about 2 feet above foundation-level, *Figs. 1.* In a return-wall of a lighter character, wooden piles, 10 inches by 10 inches, were

similarly driven in the deepest part, and the horizontal steel joists were dispensed with.

The excavation for the sea-wall foundation was taken out and the bottom layer of concrete was put in up to the benching at ground-level, between upright runners driven by maul. This was done in lengths of about 30 feet, which were pumped out at each fall of the tide. The upper part of the wall, from the bench at ground-level to the top, was put in by means of boxes formed of wood planks bolted together and shaped to the outline of the wall. The boxes were about 12 feet in length, and were placed with open spaces of about 15 feet between them, so that box and space alternated along the wall. The boxes were first filled with concrete, and, when the concrete had set sufficiently, the wood planking forming the box was removed and the alternate open spaces were boarded up back and front and were similarly filled with concrete, making the wall continuous. To ensure the proper junction of these several blocks of concrete, the boxes were made at each end with an internal vertical dovetail from top to bottom to unite the concrete in the boxes and spaces when the latter were filled; and the horizontal upper surface of the foundation-concrete, at ground-level, was cleaned and swept over with liquid cement before the upper layer of concrete in the boxes and spaces was placed upon it. The heads of the steel piles projected

Figs. 1.



above bottom bench-level about 1 foot 6 inches into the concrete, and formed an additional tie between the horizontal layers at ground-level. All the face-boarding for the concrete was planed and soft-soaped to give an even surface to the wall. The concrete was gauged 6 to 1 with sea-ballast, which was perfectly free from any coating or intermixture of clay. Gravel backing was placed behind the wall with an inward slope (*Figs. 1*), and was consolidated by allowing the tide to flow through it, thus deflecting a portion of the thrust on the back of the wall towards the interior of the reclamation filling. The foreshore is to be excavated later, to admit of barges lying in front of the sea-wall, *Figs. 1*.

The Author believes that this construction tends to anchor and sustain the wall, as well as to prevent it from overturning; that it is especially applicable to a weak soil; and that the wall can thus be made lighter and with foundations of less depth than would be required otherwise, realising a considerable economy on the whole result. The cost of the wall was within £4 10*s.* per lineal foot.

The Author is indebted to the Resident Engineer, Mr. G. E. Eachus, junior, for his efficient co-operation and superintendence of the works.

The Paper is accompanied by a tracing, from which the Figure in the text has been prepared.

(*Paper No. 3323.*)

"Some Experiments on Conjugate Pressures in Fine Sand, and their Variation with the Presence of Water."

By George Wilson, D.Sc., Assoc. M. Inst. C.E.

The results of experimental investigation have hitherto, in general, tended to show that the actual lateral pressure of earthwork is much less than that deduced from theoretical considerations. The assumptions upon which the theoretical treatment of the subject is based are, however, just those which are not usually realized in experiment, and hence the results of the two are not capable of exact comparison. Formulas based upon the Coulomb wedge-theory give the maximum thrust which could occur if the wedge broke off along a certain plane, and fracture does not necessarily tend to take place in that manner; whilst, if the Rankine formula is used, care must be taken to eliminate the effect of the wall itself in supporting the mass, and to obtain the material in the condition specified by Rankine—precautions which apparently have not hitherto been observed.

Two noticeable features of most of the experiments made with the object of obtaining the lateral pressure are (1) the large departures of some of the results from the mean value, and (2) the difference between the mean result and the value given by theory. The Author, therefore, undertook the experiments described in the following Paper, in the first instance to examine the causes which tend to produce these departures from the mean result, and second, having obtained the necessary information on this head, to measure the ratio between the horizontal and vertical pressures and to compare it with the theoretical ratio.

The expression obtained by Rankine[1] to represent the least intensity, p, of the horizontal pressure necessary for equilibrium at any depth, h, in a mass of granular material of weight w lbs. per cubic foot is, when the ground surface is horizontal,

$$p = \frac{1 - \sin \alpha}{1 + \sin \alpha} w h,$$

[1] Rankine, "Applied Mechanics," p. 216.

where p is in lbs. per square foot, and a is the natural angle of repose of the material. This formula refers to the horizontal pressure at a sufficient distance from the neighbourhood of any confining walls, and depends upon the following principle:[1]—"The resistance to displacement by sliding along a given plane in a loose granular mass, is equal to the normal pressure exerted between the parts of the mass on either side of that plane, multiplied by a specific constant." The specific constant is the coefficient of friction of the mass, and is equal to the tangent of the angle of repose.

It will be seen that the resistance to sliding, even in the driest sand obtainable for ordinary use, is never completely expressed by the foregoing statement; there is always an adhesive action due to moisture deposited on the surface of the grains, and hence even fine dry sand will not give results consistent with theory unless precautions are taken to reduce this action to a negligible quantity. Again, if the size of the grains is increased, to reduce this action, the dimensions of the mass experimented on must be likewise increased before the material will fulfil the conditions enunciated.

Boussinesq[2] has presented the Rankine formula in a more developed form, to include the action of a vertical wall-face, thus:—

Let ϕ = the angle of friction between the wall-face and the sand, and $a^2 = \dfrac{1 - \sin a}{1 + \sin a}$; and let x = the horizontal distance from the wall-face, and h = the vertical depth below the surface.

Then for x less than $a\,h$—

$$\text{Horizontal pressure} = \frac{w\,(h + x \tan \phi)\,a^2}{1 + a \tan \phi}$$

$$\text{Vertical} \quad \text{,,} \quad = \frac{w\,(h + x \tan \phi)}{1 + a \tan \phi}$$

Ratio = a^2 as before, whilst at the wall-face $x = o$, and these become $\dfrac{w\,h\,a^2}{1 + a \tan \phi}$, $\dfrac{w\,h}{1 + a \tan \phi}$, and the tangential force in the face $= \dfrac{w\,a^2\,h \tan \phi}{1 + a \tan \phi}$. Thus it may be seen that the influence of the walls will not affect the ratio of the pressures, although it affects the pressures themselves.

The measurement of the natural angle of slope of the sand was carried out by the Author in two ways. First, the sand was

[1] Rankine, "Applied Mechanics," p. 212.
[2] Minutes of Proceedings Inst. C.E., vol. lxv. p. 214.

placed in a box having a sliding end, and the box was tapped, after which the end was opened gently. When the sand had assumed a position of rest the slope was measured by taking vertical offsets at three points $4\frac{1}{2}$ inches apart. The values obtained were:—

—	Tan a.	a.		Sin a.
		°	′	
Maximum	0·647	32	53	0·543
Minimum	0·567	29	32	0·493
Mean	0·618	31	44	0·526

Six experiments were made, the sand being allowed to stand for periods of time varying between a few minutes and 19 hours. In the second method, the sand was placed in a heap and tapped; the following are the values of tan a obtained in this way:—

—	Tan a.	a.		Sin a.
		°	′	
Maximum	0·590	30	36	0·509
Minimum	0·578	30	0	0·500
Mean	0·584	30	16	0·504

From these results the following are the values obtained for $\frac{1 - \sin a}{1 + \sin a}$:—

Maximum.	Minimum.	Mean.
0·339	0·296	0·320

The first experiments made by the Author were carried out on a small scale in a box holding about 2 cwts. of sand, and wide enough to avoid the influence of the sides upon the results. The sand chosen was that known as fine Calais sand, which probably most closely resembles the granular mass postulated by Rankine. The apparatus used was small, so that a large number of experiments could be made under different conditions. The results obtained are not of direct quantitative value, but were of importance in determining the best arrangement for the later experiments. The horizontal pressure was deduced from measurements of the limiting friction between the sand and a thin steel scale 18·4 inches in length by $2\frac{1}{4}$ inches in width and 0·04 inch in thickness, inserted vertically to different depths in the sand. The pull necessary to withdraw the scale in each case was carefully measured. In order to obtain the coefficient of friction, μ, between the metal and the sand, the scale was then laid horizontally under

a variable load and the pull necessary to move it was again determined. The results obtained were of the form—

$$\mu = d + c p^{-0 \cdot 62}$$

where p = the pressure and μ = the coefficient of friction between the sand and the scale, d and c being constants.

If it is assumed that the lateral pressure $p = k\,h$, where k is a constant, then the value of the tangential stress on the scale, when in the vertical position, would be—

$$\mu p = d p + c p^{0 \cdot 38} = d\,k\,h + c\,k^{0 \cdot 38}\,h^{0 \cdot 38}$$

and integrating between o and h—

$$\text{Total pull} = \text{P} = \frac{d\,k\,h^2}{2} + \frac{c\,k^{0 \cdot 38}}{1 \cdot 38}\,h^{1 \cdot 38}$$

which may be written $\quad \text{P} = \text{M}\,h^2 + \text{N}\,h^{1 \cdot 38}$.

Next, considering the pull necessary to withdraw the scale when vertical, this form of equation for P was found to fit the mean experimental values with reasonable accuracy, thus—

$$\text{P} = 0 \cdot 434\,h^2 + 29 \cdot 18\,h^{1 \cdot 38}$$

the values being the following :—

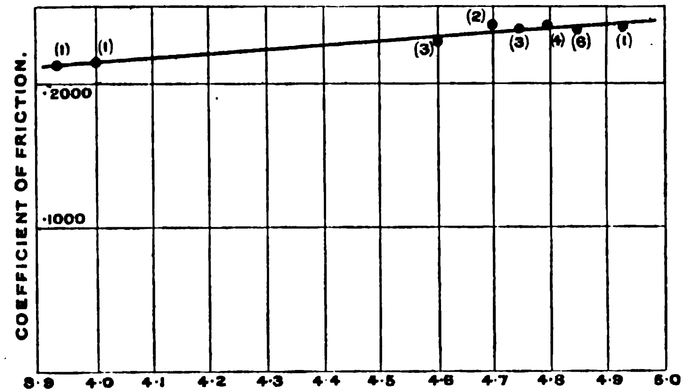
Depth in Inches.	P by Experiment.	$\text{P} = 0 \cdot 434\,h^2 + 29 \cdot 18\,h^{1 \cdot 38}$.	Difference.
			Per Cent.
3	187·5	186·8	+0·51
5	279·8	279·8	..
7	442·4	449·1	−1·52
9	640·5	640·4	..

Thus instead of P varying as h^2 it is seen that there is a second term introduced, which will become relatively smaller as h increases. Thus at great depths it follows that the total horizontal pressure will vary as the square of the depth, but near the surface it will not follow this law exactly, but will be reduced somewhat. Two causes contribute to this effect, viz. :—(1) The sand being continually re-made, and its grains having a large affinity for moisture, it would naturally be affected by changes in the hygroscopic condition of the atmosphere, and any moisture condensed would, after the manner already explained, tend to hold the grains together; and (2) variations in the rate at which the pull is increased would naturally affect the resisting power of grains bound together in this manner.

Experiments were made to investigate these points, using glass

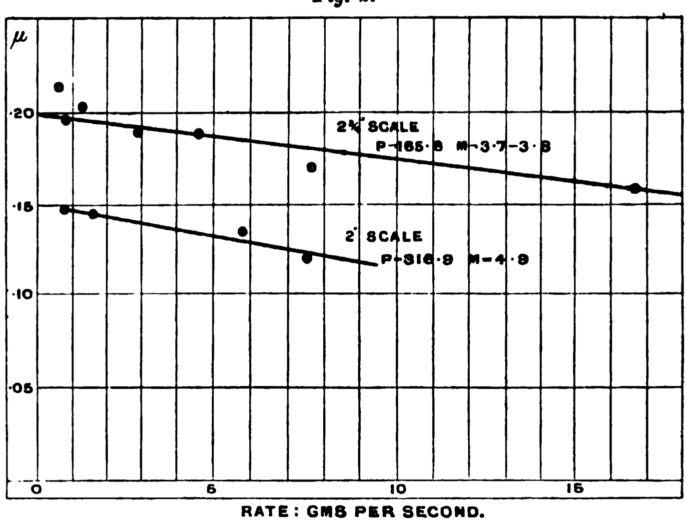
scales instead of steel, as the effect of the moisture on the glass is greater than on steel. Keeping the pressure and the rate of increase of pull constant, the results obtained are shown in *Fig. 1.*

Fig. 1.



MOISTURE: GRAINS PER CUBIC FOOT OF AIR.
PRESSURE 107 GMS. PER SQ. IN. RATE 1·8–1·9 GMS. PER SEC.

Fig. 2.

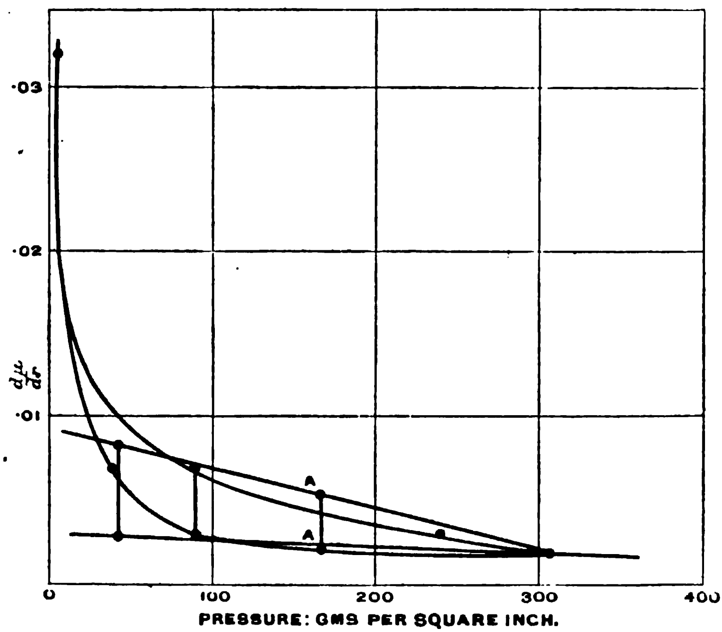


Under the conditions of this experiment the alteration was 0·0̇308 for an increase of moisture of 1 grain per cubic foot of air. Examples of the results of one hundred and fifty experiments on the effect of the rate of loading are shown in *Fig. 2.* In every case the

value of the coefficient diminished as the rate of loading increased. That the rate of change of the coefficient of friction with respect to the rate of loading, or $\frac{d\mu}{dr}$, decreases as the pressure increases is shown by *Fig. 3*. Thus with dry sand these effects ought to be negligible at high pressures, whilst with wet sand the higher the pressure the less is the effect of water, and consequently the greater the ratio of the pressures as the pressure increases.

Rankine[1] has mentioned the effect of water on the stability of the material, but apparently had not completely realised its

Fig. 3.

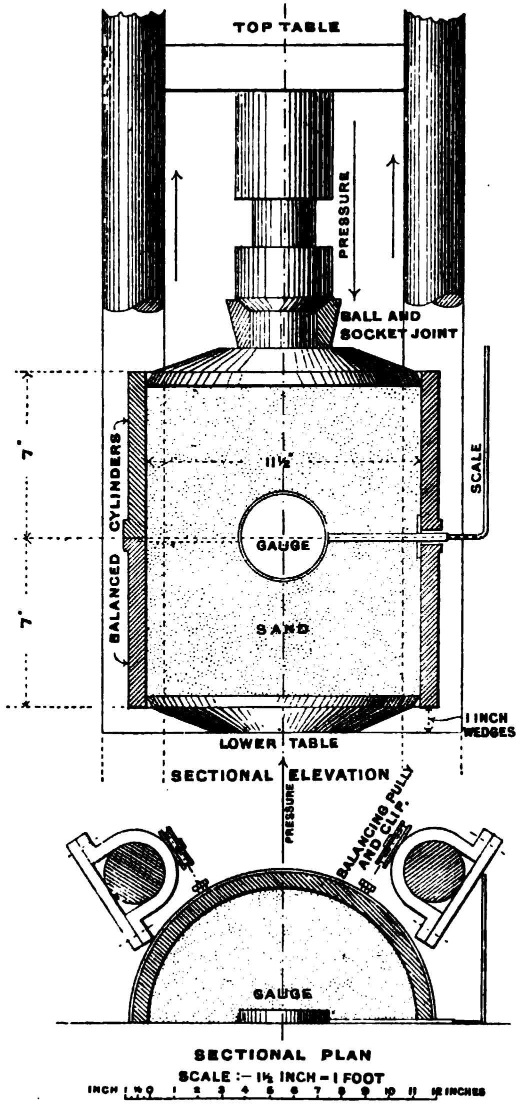


character. Microscopical examination of wet grains will show the moisture enveloping the grains like a skin. On two grains being placed together a neck of moisture is formed between them and the surface-tension across this neck pulls the grains together. This is the cohesive force which tends to hold the mass together and to increase its angle of repose. A similar effect can be observed with hollow glass globes about ½ inch in diameter suspended by parallel threads. A drop of water placed between

[1] Rankine, "Civil Engineering," p. 316.

the globes will enable the threads to assume a considerable angle with the vertical before the globes are separated. Further confirmation of this action was obtained by means of a whirling table upon which sand was scattered. By breathing upon the sand and the surface of the table the coefficient of friction was increased from 0·36 to 1·9. The effect of water in the sand, therefore, reduces to a traction between each pair of adjacent grains. If the water is increased the force will increase up to a certain point; further additions to the percentage of water in the mixture will reduce the force, but as long as the interstices are not entirely filled with water there will be some force acting between the grains, and hence the ratio of horizontal to vertical pressure should be less than that for dry sand.

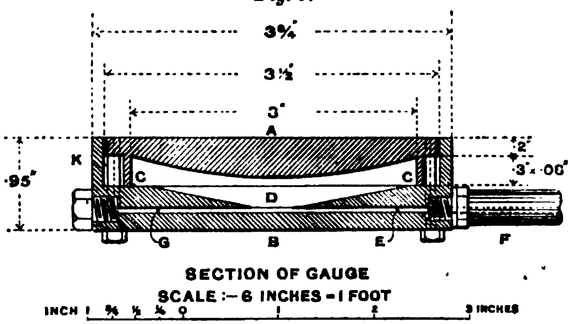
Figs. 4.



The information gained from these preliminary experiments enabled the Author to construct an appliance to test these conclusions. To eliminate

or reduce to negligible dimensions the "rate of loading" and "atmospheric moisture" effects, it was necessary to use large pressures, and the apparatus was therefore used in conjunction with a 100-ton testing machine. Pressures equal to that due to a depth of 1,341 feet were reached. The appliance consists of a vertical cylinder, in which the material was compressed by means of two flat disks, which were forced together between the compression tables of the machine, as shown in *Figs. 4.* The ratio of the intensities of the horizontal and vertical pressures was measured by means of a suitable pressure-gauge inserted at the centre of the mass of sand. A satisfactory gauge was procured only after several different designs had been tried and rejected. It is necessary that the motion of the pressure face of the gauge shall be very little, in order to keep the effect of the friction of the sand within reasonable limits.

Fig. 5.



SECTION OF GAUGE
SCALE :– 6 INCHES = 1 FOOT

For, with a weak gauge, it is possible by tapping to cause the gauge-face to deflect too far, and then the friction of the sand acting against it prevents its return to the correct position. A section of the gauge used is shown in *Fig. 5.* Two forged tool-steel disks, A and B, were turned to shape and separated by a ring, CC, turned out of the disk A to a definite depth and thickness. The chamber D between the disks was filled with mercury, and was connected by means of the passage E to the gauge-tube F. The tube F, of steel, has a length of 4 or 5 inches and then is replaced by a thick glass tube of fine bore, which is bent to a right angle and is inclined at an angle of 45° to the face of the disk A. Thus, whether the face of this disk is horizontal or vertical, the gauge-tube is always inclined at an angle of 45°. A scale was fixed on the gauge-tube having graduations 0, 1, 2, 3, etc., spaced $\frac{3}{8}$ inch apart. The passage G was used for filling the gauge. The disks

A and B were held together by twelve set-screws, and as the edge of the ring CC and the face of disk B were hardened and ground together a perfectly tight fit was obtained. The guard-ring K served to keep the side pressures from influencing the results appreciably. Any pressure on A and B compresses the ring CC and drives the mercury up the glass tube to a certain height. It is thus possible, by driving the mercury up to the same height each time, to adjust the load with considerable accuracy.

In order to get over the difficulty introduced by the support given to the sand by the vertical walls of the chamber, these walls were suspended and balanced so that they were free to move vertically with the sinking of the sand, *Figs. 4*; and, to eliminate the effects of other disturbing influences as far as possible, the walls were gently tapped during the application of the pressure. In *Figs. 4* the apparatus is shown in position ready for use, with a ball-and-socket joint on the top plate to equalise the distribution of the thrust.

When making an experiment, the base-plate and lower ring were first put into position, the latter being supported on suitable packings. Sand was then introduced and rammed and tapped until no further settlement was observed. The gauge was then placed in position, with its faces horizontal and the gauge-tube projecting freely through the hole in the side of the rings. The upper ring was then put on and filled with well-rammed sand. The top disk and ball-and-socket joint were then added, and the whole was rammed home by putting on the load whilst the packings were still in position. The effect of the walls in supporting the sand was very noticeable, as a much greater load was required to bring the mercury up to any assigned mark when the packings were in position and the walls rigidly supported than when they were free. After the wedges had been removed the mercury was driven up to the first mark by applying the pressure. On reaching this point the load was taken and the pressure was again applied until the next mark was reached. By this means the increment of load necessary to raise the mercury from any one mark to the next was obtained. The gauge was then set with its faces vertical and the process was repeated. By taking increments of load, zero errors and errors due to initial want of balance were eliminated. The ratio of the increments of load in the two cases then gives the ratio of the pressures, *i.e.*, the ratio of the horizontal and vertical pressures in the material.

Experiments were made in this manner with dry sand and with sand containing (1) 6 per cent., (2) 12 per cent., and (3) 17 per

cent., by weight, of moisture. It was calculated that if the grains were regular, 18 per cent. to 19 per cent. of water would fill up the interstices in the sand and reduce it to the consistency of mud. When actually mixed with 18 per cent. of water it was found that the water drained out and could not be held in the sand; 17 per cent., however, remained in the mixture.

The following are the results obtained in the various experiments:—

(1) Dry Sand.

(a) *Gauge-face Horizontal.*

—	Scale Divisions.			
	1 to 2.	2 to 3.	3 to 4.	4 to 5.
Increment of load in tons . . .	3·060	2·750	2·78	2·68
,, ,, ,, . . .	2·795	2·865	2·83	2·80
,, ,, ,, . . .	2·660	2·970	2·985	2·905
,, ,, ,, . . .	2·900	2·700	3·050	2·990
Mean increment of load in tons .	2·853	2·821	2·911	2·844

(b) *Gauge-face Vertical.*

—	Scale Divisions.			
	1 to 2.	2 to 3.	3 to 4.	4 to 5.
Increment of load in tons . . .	8·17	8·83	8·39	8·72
,, ,, ,, . . .	8·69	8·95	8·19	..
,, ,, ,, . . .	9·42	8·71	9·07	..
,, ,, ,, . . .	9·09	9·98	9·11	8·20
,, ,, ,, . . .	9·32	9·59	9·79	..
,, ,, ,, . . .	9·07	8·76	8·64	..
,, ,, ,, . . .	8·90	9·23	9·52	..
,, ,, ,, . . .	10·19	9·86	9·92	..
Mean increment of load in tons .	9·11	9·24	9·08	8·46

Hence mean ratios of horizontal to vertical pressures are:—

—	Scale Divisions.				
	1 to 2.	2 to 3.	3 to 4.	4 to 5.	Means.
Ratios	$\frac{2·853}{9·11}$	$\frac{2·821}{9·24}$	$\frac{2·911}{9·08}$	$\frac{2·844}{8·46}$	$\frac{2·857}{8·97}$
i.e.	0·313	0·305	0·320	0·336	0·319

Therefore mean experimental ratio for dry sand = 0·319.

(2) SAND WITH 6 PER CENT. OF WATER, BY WEIGHT.

(a) *Gauge-face Horizontal.*

—	Scale Divisions.				
	2 to 3.	3 to 4.	4 to 5.	5 to 6.	6 to 7.
Increment of load in tons . .	1·53	1·78	1·80	1·73	1·95
,, ,, ,, . .	1·61	1·69	1·87	2·00	1·93
,, ,, ,, . .	1·55	1·78	1·92	2·07	2·07
Mean increment of load in tons	1·56	1·75	1·86	1·93	1·98

(b) *Gauge-face Vertical.*

—	Scale Divisions.				
	2 to 3.	3 to 4.	4 to 5.	5 to 6.	6 to 7.
Increment of load in tons . .	5·83	7·55	9·27	9·01	8·13
,, ,, ,, . .	6·38	8·19	9·87	8·67	8·07
,, ,, ,, . .	6·30	8·43	9·65	8·89	8·01
,, ,, ,, . .	6·20	8·35	10·00	8·84	8·54
Mean increment of load in tons	6·18	8·13	9·70	8·85	8·19

Hence ratios of horizontal to vertical pressures are :—

—	Scale Divisions.					
	2 to 3.	3 to 4.	4 to 5.	5 to 6.	6 to 7.	Means.
Ratios	$\frac{1\cdot56}{6\cdot18}$	$\frac{1\cdot75}{8\cdot13}$	$\frac{1\cdot86}{9\cdot70}$	$\frac{1\cdot93}{8\cdot85}$	$\frac{1\cdot98}{8\cdot19}$	$\frac{1\cdot82}{8\cdot21}$
I.e.	0·253	0·215	0·192	0·218	0·242	0·221

Therefore mean experimental ratio is 0·221.

(3) SAND WITH 12 PER CENT. OF WATER, BY WEIGHT.

(a) *Gauge-face Horizontal.*

—	Scale Divisions.				
	0 to 1.	1 to 2.	2 to 3.	3 to 4.	4 to 5.
Increment of load in tons . .	1·855	2·025	2·015	2·045	2·065
,, ,, ,, . .	1·960	2·075	2·040	2·233	2·040
,, ,, ,, . .	1·950	2·220	2·135	2·140	2·115
,, ,, ,, . .	1·930	2·170	2·310	2·120	2·160
Mean increment of load in tons	1·924	2·123	2·125	2·135	2·100

(*b*) *Gauge-face Vertical.*

—	Scale Divisions.		
	0 to 1.	1 to 2.	2 to 3.
Increment of load in tons . . .	8·65	8·85	8·08
" " " . . .	10·69	8·67	..
" " " . . .	13·22	9·70	..
" " " . . .	10·67	9·34	..
" " " . . .	10·29	9·54	..
Mean increment of load in tons .	10·71	9·22	8·08

Readings not taken past division 3.

Mean increment of load for one scale-division, gauge-face horizontal = 2·081. Mean increment of load for one scale-division, gauge-face vertical = 9·79. Hence mean ratio of horizontal to vertical pressures $= \frac{2 \cdot 081}{9 \cdot 79} = 0 \cdot 212$.

It will be seen that as the pressure increases the effect of the water is diminished and the ratio is increased.

Thus, for scale-division 0 to 1 the ratio is $\frac{1 \cdot 924}{10 \cdot 71} = 0 \cdot 179$; for scale-division 1 to 2 it is 0·233; and for scale-division 2 to 3 it is 0·263.

(4) Sand with 17 per cent. of Water, by Weight.

(*a*) *Gauge-face Horizontal.*

—	Scale Divisions.				
	0 to 1.	1 to 2.	2 to 3.	3 to 4.	4 to 5.
Increment of load in tons . .	2·40	2·06	2·02	2·30	2·02
" " " . . .	2·09	2·32	2·44	2·30	2·21
" " " . . .	2·10	2·23	2·45	2·66	2·39
Mean increment of load in tons	2·20	2·20	2·30	2·42	2·21

(*b*) *Gauge-face Vertical.*

—	Scale Divisions.		
	0 to 1.	1 to 2.	2 to 3.
Increment of load in tons . . .	6·87	7·27	6·86
" " " . . .	8·80	8·37	7·66
" " " . . .	8·51	7·98	7·67
" " " . . .	10·00	9·09	8·07
Mean increment of load in tons .	8·54	8·18	7·57

Hence mean increment of load for one scale-division, gauge-face horizontal = 2·266. And mean increment of load for one scale-division, gauge-face vertical = 8·096.

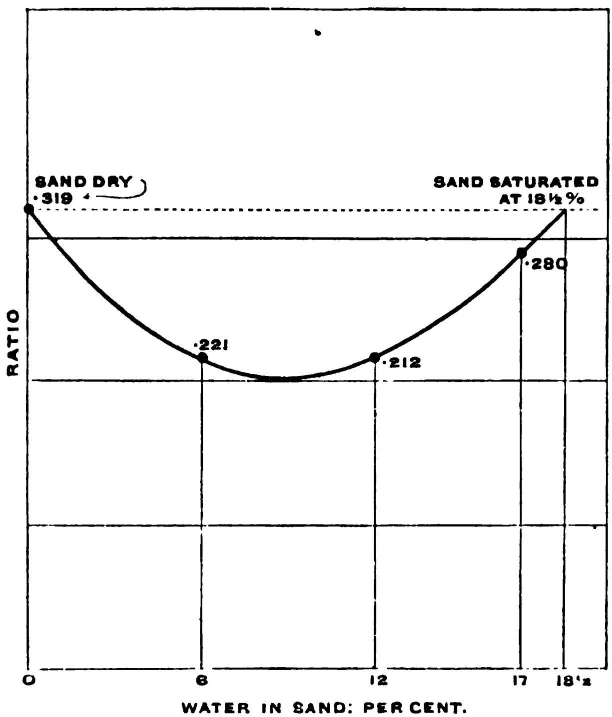
Therefore mean experimental ratio $= \dfrac{2 \cdot 266}{8 \cdot 096} = 0 \cdot 280$.

These results are represented graphically in *Fig. 6*. They may be expressed by the equation—

$$(k - 9 \cdot 3)^2 = 740\,(R - 0 \cdot 202),$$

where k is the percentage of moisture and R the ratio.

Fig. 6.



The ratios obtained by experiment may now be compared with those deduced by means of the Rankine theory from measurements of the angle of slope of the sand :—

(1) Dry Sand.

——	Maximum.	Minimum.	Mean.
Ratio by Rankine theory	0·339	0·296	0·320
Ratio by experimental measurement of the ratio of pressures	0·336	0·305	0·319

Thus, with a material as postulated by the theory, the results are comparable, and agree remarkably. It is evident, therefore, that the causes of the disagreement generally found are chiefly—

(*a*) The support of the walls;
(*b*) The influence of moisture;

and in experiments—

(*c*) The influence of the rate of loading.

(2) WET SAND.

	Percentage of Water.				
	0.	6.	12.	17.	18·6.
Mean ratio by empirical formula . . .	0·319	0·216	0·211	0·282	0·319
Mean ratio by experiment	0·319	0·221	0·212	0·280	..

The largest difference between the ratio as obtained by the formula and by experiment is therefore about 2 per cent.

The minimum value of R would thus be $\frac{1}{5}$, very nearly, when the interstices are half filled up.

It is thus seen that the horizontal thrust is greatest when the sand is dry, or when it is saturated with water; that it diminishes to a minimum between these limits and then increases again; and that the value of this decrement for any particular percentage diminishes as the pressure increases. In actual practice the sand or earth would probably be in a condition neither dry nor very wet, and hence the pressure would be less than that indicated by theory.

In the light of the foregoing experiments it can be seen that experiments on pressure-boards or miniature walls, backed by a fine material such as sand, cannot be expected to give satisfactory results unless great pressures are used and the local influence of the walls is eliminated. If a larger-grained material, such as gravel, is used, in order to get over the moisture difficulty, then, unless the dimensions of the experiment are increased in proportion, the results are of little value, since the angle of repose of a small quantity of material with large grains may be dependent to a large extent upon geometrical considerations. Nor, except by the light they throw on general principles, will the experiments of the Author assist in determining the actual pressure on any wall; they will indicate the maximum value of the ratio of horizontal to vertical pressure, which, of course, is independent of the proximity of the wall; but, since the vertical pressure is

dependent on this proximity for the material in question, this is not of much assistance unless wall-friction is neglected. However, since they verify the expressions given by Rankine and Boussinesq for the particular case of dry sand, they may establish a certain amount of confidence in the corresponding expressions which take into account the influence of the wall itself.

It may be seen, however, that the action of water in a fine-grained material follows a well-defined law, and that, with a certain amount of dampness in the backing of a wall—an amount such as is probably obtained with ordinary drainage—the ratio, and hence the horizontal pressure, will be less than that for dry material. It appears to the Author that the only method by which reliable results can be obtained is to construct gauges, on a similar principle to the diaphragms or sacs used in the "Emery" testing-machine, and to insert these behind walls during construction. Records of actual pressures realized by such gauges would surely form a valuable addition to the knowledge of this subject. The experiments described in this Paper were carried out in the Whitworth Laboratory of the Owens College, Manchester.

The Paper is accompanied by six diagrams, from which the Figures in the text have been prepared.

(*Paper No.* 3325.)

"Tide-Gauges in Northern Climates and Isolated Situations."

By William Bell Dawson, M.A., D.Sc., Assoc. M. Inst. C.E.

In order to obtain a reasonably complete knowledge of the tides of the world as a whole, it will be necessary to investigate the tides of the Arctic regions, some of which are of great range; and it may also be found that localities on exposed coasts are of primary importance, from a tidal point of view, in securing the necessary data. As tidal information can now be obtained so much more completely and satisfactorily by means of self-registering instruments than by any method of direct readings on a vertical scale, these have come into very general use. It will thus be necessary to establish such tide-gauges to work under winter conditions, and in situations where there are no artificial facilities, such as wharves, to take advantage of. It may therefore be of interest to describe the methods by which these difficulties have been overcome in a sufficient degree to secure continuous records throughout the winter from registering tide-gauges established by the Tidal Survey of Canada, which has been under the direction of the Author for 7 years, ever since its initial or experimental stage.

The tides on the eastern coasts of Canada present a remarkable variety in height, some of them—in the Bay of Fundy—having as great a range as is to be found anywhere; and others, in parts of the Gulf of St. Lawrence, being almost inappreciable except at spring-tides. This has made it necessary to establish a relatively large number of principal tidal stations, eight in all, which are kept in continuous operation throughout the year; but their number will the better serve to exemplify the requirements of extreme climate, isolated situations, and the deficiency of permanent harbour-works in their various aspects. Only one of these gauges stands on masonry, three of them are in harbours where wharves of timber-work are available for their support,

and four others were built on rocky shores or against cliffs where no artificial facilities existed. Of these four, three are in localities to which there is no access at any time except by sea, and which are entirely inaccessible for about 5 months in winter; with two of them, however, there is telegraphic communication. The distances from headquarters at Ottawa range between 285 miles and 1,590 miles by the ordinary routes of travel, leaving out of account the more recently erected tidal stations on the Pacific coast, at a distance of 2,780 miles in the opposite direction. The tide-gauges are placed in situations where they command extensive land-locked areas or large estuaries, and serve as reference-stations for the ports in these areas. Their situations are shown on the outline Map, *Fig. 1.*

The general system adopted is to secure continuous records from the principal stations, for harmonic analysis and the primary calculation of tide tables, and to obtain the relation of other ports to these by means of shorter series of observations at secondary stations during a few months in the summer season. Twenty-eight secondary stations have been established in different years, and these stations are also furnished with self-registering instruments, but of a simpler type. The records secured at these stations are used to determine tidal differences and ratios with the principal stations, which may either prove to be constant or to vary in terms of some astronomical period. They serve also to ascertain the extent of the region which can most suitably be referred to each of the principal stations.[1]

At the secondary stations the small type of recording instrument used is set on the top of a tide-column 10 inches by 20 inches in cross-section, built of planking and sheltered in a zinc-covered box with hinged front and lid. At these stations some difficulty occurs from the great range of temperature, from frost at night at the beginning of the season to the excessive heat of midsummer, which makes the driving-clock vary as much as 2 minutes in the day, as these smaller instruments are not compensated. Another difficulty is caused by the vertical movement of the water in the tide-column—arising from the action of the waves, especially where a sufficient depth of water cannot be secured.

General Description of the Tide-Gauges.—The instrument used to secure a continuous record of the tide consists essentially of a

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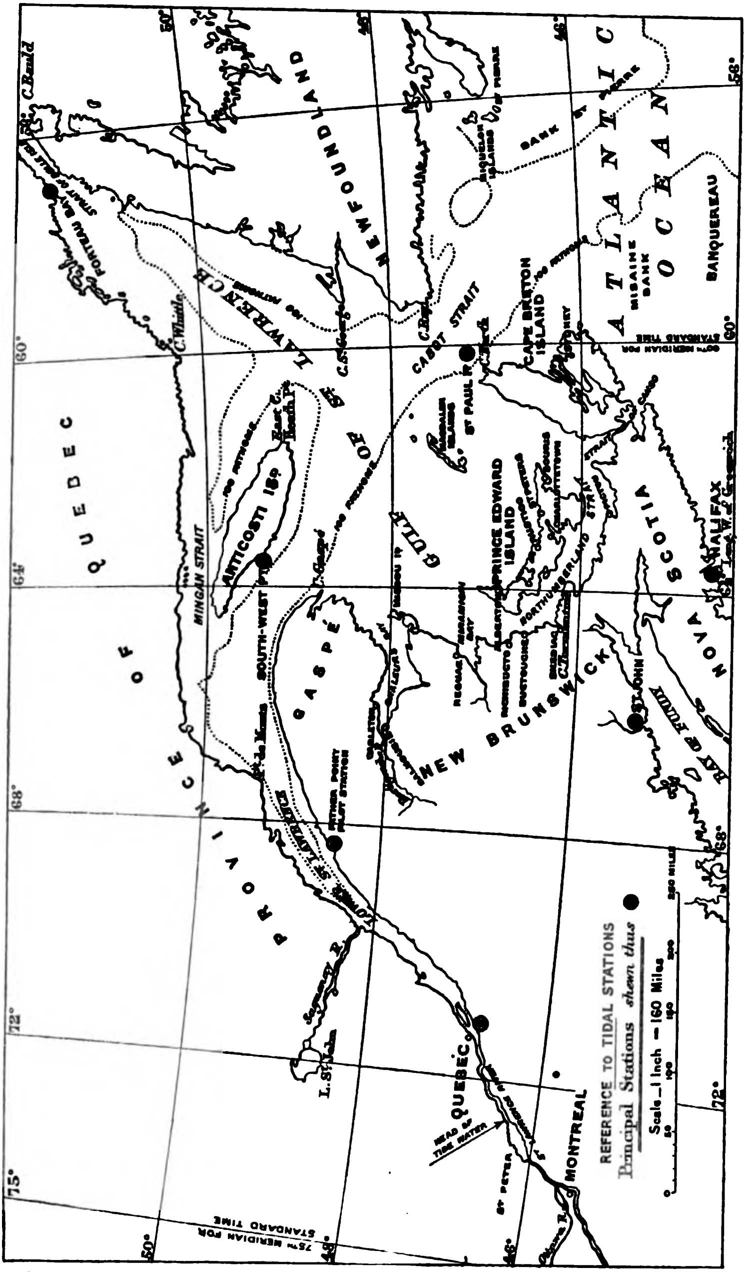
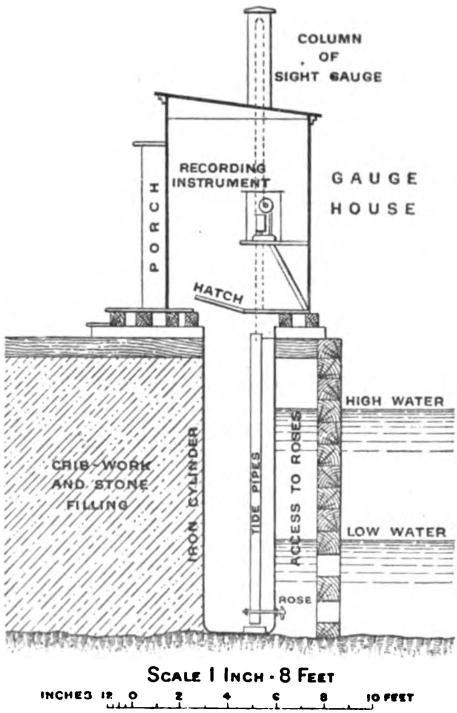
[1] See Paper on "The Character and Progress of the Tides in the Gulf and River St. Lawrence." 1897. Royal Society of Canada, vol. iii., pp. 51–68.

Fig. 1.


PROVINCE OF QUEBEC
NEWFOUNDLAND
GULF OF ST LAWRENCE
ATLANTIC OCEAN
GASPÉ
NEW BRUNSWICK
NOVA SCOTIA
ANTICOSTI ISᴰ
PRINCE EDWARD ISLAND
CAPE BRETON ISLAND
MAGDALEN ISLANDS
MINGAN STRAIT
CABOT STRAIT
NORTHUMBERLAND STRAIT
BAY OF FUNDY
BANQUEREAU
MISAINE BANK
QUEBEC
MONTREAL
HALIFAX
ST JOHN
HEAD OF TIDE WATER
FATHER POINT PILOT STATION
SOUTH-WEST PT
ST PAUL I.
STRAIT OF BELLE ISLE
60TH MERIDIAN FOR STANDARD TIME
75TH MERIDIAN FOR STANDARD TIME
REFERENCE TO TIDAL STATIONS
Principal Stations shewn thus
Scale_1 Inch = 160 Miles

revolving cylinder, actuated by clockwork, on which the rise and fall of the tide is marked by a pencil moving parallel to its axis, on a scale reduced to a convenient range by means of gearing. The movement of the tide is communicated to this pencil from a float placed within a vertical pipe for protection. An inlet suitably contrived admits the sea-water to this pipe. A second pipe, having a similar inlet and in every way a duplicate of the first, is placed beside it for the "sight gauge," to be described later. A general modification of the working conditions arises at the outset from the necessity of heating the gauge sufficiently to keep the tide-pipes from freezing in winter. To effect this, the tide-pipes have to be of moderate diameter, and surrounded throughout their whole height (which extends to several feet below low-water) by an air-space or jacket of warm air. The arrangement adopted as most suitable is to use galvanized wrought-iron pipes, 6 inches in diameter, enclosed in a vertical iron cylinder, 3 feet in diameter, which must of course be water-tight, and is conveniently made of a length of old boiler, this size being readily obtained, as it is much used in saw-mills. The iron cylinder is lined inside with wooden lagging to make it non-conducting. It is large enough to admit a man to examine the lower end of the tide-pipes, or to carry out repairs, a ladder or cross-bars being provided for the purpose, *Fig.* 2.

Fig. 2.

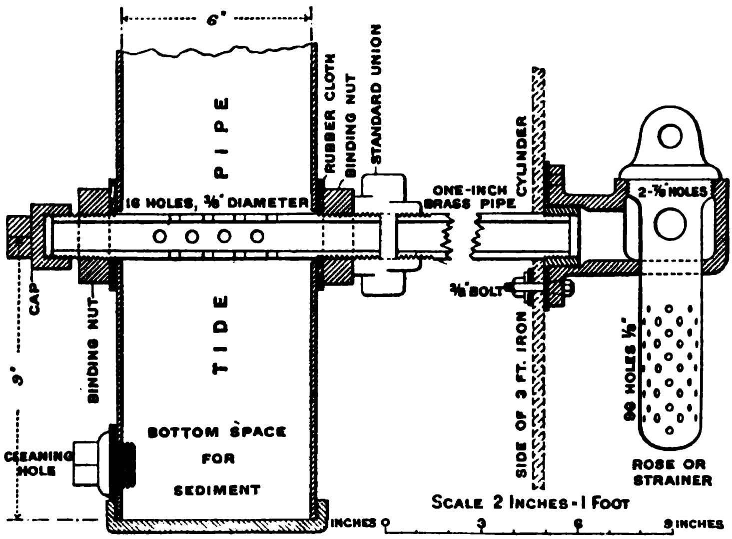


SECTION OF GAUGE-STATION.

The water is admitted to the tide-pipes by a horizontal inlet-

pipe which passes out through the side of the cylinder and is fitted with a strainer or rose on the outside, *Fig. 3*. This is so arranged as to enable the inlet-pipe to be cleaned from inside, and the rose, being set vertically through its collar, can be unscrewed on the outside and raised out of the water to be cleaned. These fittings are of brass, and are jointed with gasket or rubber-cloth to prevent metallic contact with the ironwork. The holes in the rose are small, and the water has to pass through a second set of small holes in the sides of the inlet-pipe, the object being to reduce the movement of the water in the tide-pipes caused by the waves.

Fig. 3.



SECTION OF INLET-PIPE.

A small house, 6 feet square, is set on the top of the iron cylinder to protect the tidal instruments, *Fig. 2*. It is built with a framework of ordinary scantling, but the walls require to be substantial to keep out the cold and wet. They are made of two thicknesses of 1½-inch board, tongued and grooved, the inner boarding being set horizontally and the outer vertically. Between these a layer of roofing-felt or tarred paper is placed. One or two small windows are needed, which, as they do not require to be opened, can be made quite air-tight. They are fitted with double sashes, with an air-space between, and are protected on the outside by a sliding wooden shutter, to be closed in stormy weather to

keep the sea from breaking the glass. The door is made of the same boarding as the house-wall, laid across in two directions. An outer or porch door is fitted, having a frame which gives it an offset of a few inches from the other door, thus securing warmth by means of a tightly-enclosed air-space. The roof is flat, with only a slight slope, as it is necessary to stand upon it to examine the upper end of the sight-gauge. It is covered with sheet-zinc, with a second covering of painted canvas. It is an advantage to have an inner ceiling of well-fitted tongued-and-grooved boarding about 3 inches below the outside roofing, to enclose an air-space at the top. This prevents sweating or condensation, which may give rise to an inconvenient drip of water.

In most cases the house is supported by the cylinder itself, as this usually affords a better foundation for it than can otherwise be secured. The joint between the iron and the woodwork requires to be well caulked to make it air-tight, the air required within the house being admitted by special ventilating-pipes. The floor of the house closes the top of the cylinder to keep out the damp air from below, and a hatch in the floor gives access to the interior of the cylinder, which forms an open well around the tide-pipes. The need of repair for such a house usually arises from shrinkage of the wood, letting through the air or damp. This may be largely obviated in advance by using well-seasoned wood, and by thoroughly painting the boarding of the walls, and jointing it with white lead. It can readily be repaired, however, by putting on an outside covering of clap-boards or shingles.

The Recording Instrument.—The type of recording instrument which can be used is conditioned, in the first instance, by the comparatively small size of the tide-pipes, which are 6 inches in diameter. It is accordingly necessary to have the mechanism of the recording instrument sufficiently sensitive to respond to a tide-float of small size. Further, a pendulum clock to drive the instrument is inadmissible, on account of the vibration in exposed situations, or the jarring of vessels against the timber wharves on which the gauges may be placed. A balance-wheel escapement is therefore essential, and with this escapement a mainspring is used, rather than a weight, to drive the clock. The use of these springs is admittedly a disadvantage, as the most serious interruptions used to occur through the breakage of one or other of these springs in the clock. Also, the hairspring may rust so badly as to affect the rate of the clock, even although the instrument is always enclosed in a well-fitting glass case. Several non-rusting metals have been tried, to replace the ordinary steel hairspring,

and gold has proved the most satisfactory on the whole. The best and simplest method of meeting these difficulties is to have the driving-clock readily detachable from the body of the recording instrument, a spare clock being placed in charge of the observer. This may be regarded as essential at isolated stations, where stoppage may involve the loss of several months of tidal record.

A type of instrument was designed by the Author to meet these requirements. In this instrument the tide-gearing gives four different scales by the interchange of the smaller wheels or pinions. The tide-diagram is 9 inches in height, and the variation in the gearing gives a range of 9, 18, 27, or 36 feet in this height. The vertical cylinder around which this diagram is placed is $5\frac{3}{4}$ inches in diameter and $10\frac{1}{4}$ inches in height. The driving-clock is inside it, and the cylinder is rotated by means of a pinion at the bottom, gearing with a horizontal spur-wheel frictionally connected with the cylinder, so that the cylinder can be turned independently in order to set it to the correct hour. There is no clock-dial, but the upper edge of the diagram is divided into 5-minute spaces, and the time is read by a fixed pointer. This is a distinct advantage with unskilled observers; as there is no risk of a difference between the time on the diagram itself and the time shown by the dial, which is quite possible in most types of recording instruments. The time can be read to the nearest half-minute with reasonable care, and this is within the limit of accuracy aimed at, which is 1 minute. The tide-curve is drawn by a pencil, which is necessary where there is wave-motion; and in the design of the pencil-carriage some improvements were introduced, especially to secure distinct marking without undue friction. The whole instrument is strongly built, simple, and readily understood. In case of accident to the driving-clock, the cylinder can be removed and replaced by its duplicate in 2 or 3 minutes, without interruption to the record. This recording-instrument has now been in use for 3 or 4 years at the more remote and isolated stations, and has proved entirely satisfactory.

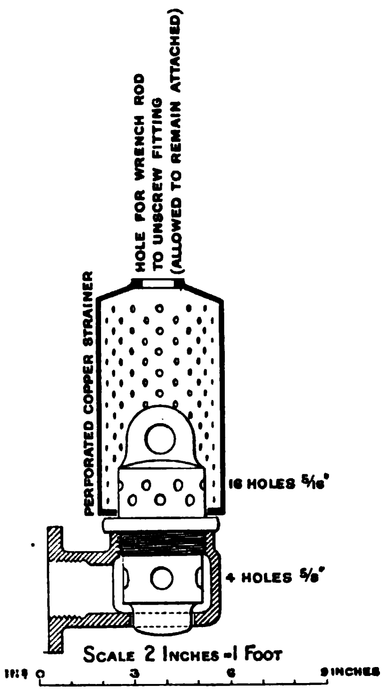
Site and Erection.—Four of the tide-gauges were erected in localities where no artificial facilities existed previously, and in those cases the general design had to be modified to meet the special circumstances. These four tidal stations were:—(1) Father Point on the Lower St. Lawrence, on a rocky shore covered at high-water. The ice here in winter frequently "shoves" and piles up to a height of 20 feet. It being therefore impossible to place the gauge far out on the rocks, a tide-well was sunk at high-water level, and was connected with the sea by a

siphon-pipe, trenched into the rock and extended beyond low-water level by a pipe laid on the bottom, to deep water. (2) Forteau Bay in Belle Isle Strait. The gauge was here set on a block of crib-work built for the purpose. The situation is comparatively sheltered, as the strait is only 10 miles wide; but the difficulty consisted in obtaining sufficient depth, as any crib-work is exposed to the action of large masses of floating ice of a thickness only limited by the depth of the water. (3) South-west Point, Anticosti Island. The gauge was here set in a natural gully in the rock, in which there was still some 3 feet depth of water at low tide. The rock itself on which the gauge-house was set was low, so that the waves frequently broke over it. (4) St. Paul Island, in Cabot Strait, between Cape Breton Island and Newfoundland. The gauge was built in a cleft in the cliff, but the exposure was severe. The gauge-house was at first placed 12 feet above the sea-level, but was carried away during a storm, and had to be raised to 25 feet above high-water level. The iron cylinder was carried up to this level also, and was connected with the gauge-house.

In selecting a site for a tide-gauge it is necessary, in the first place, to secure sufficient depth of water. If natural shelter can be had, a depth of 2 or 3 feet over the inlet of the gauge at low-water may be sufficient; but in more exposed situations as much depth as possible must be secured in order to keep the inlet from being merely in the wash of the waves at low tide. It may be possible to find a site where a good depth of water may be obtained by placing the gauge against a cliff; but on ordinary sloping beaches the most obvious method of securing depth is to build out to it. Where, however, the thickness of the ice is only limited by the depth of water in which it will float, it is difficult to get far out with a structure that will withstand its impact in heavy weather. But the difficulty of maintaining crib-work against ice should not be exaggerated; in the first place, it is found that in the early winter a heavy coating of ice forms on the structure itself, of perhaps 6 inches in thickness, extending from high- to low-water level, and this serves as a natural fender to preserve the timber from abrasion by floating ice. On the Lower St. Lawrence, long wharves of timber-work, exposed to a run of ice in a tidal current of some 4 knots an hour in each direction, sustain remarkably little damage from ice. When again a crib-wharf is shorter, it may become surrounded by "standing ice," which freezes out from the shore, and acts as a buffer against the floating ice beyond. Under the worst conditions, as at

Forteau Bay in Belle Isle Strait, crib-work may still be maintained by watchfulness; and when threatened by heavy blocks of ice, these may be fended off by poles of 3 or 4 inches in diameter, planted in the bottom at a distance of 1 foot or 2 feet from the face of the crib, and resting against its edge at the top. Such poles have considerable spring, and will throw off large blocks of ice even in heavy weather. This crib-work at Forteau Bay became so far damaged and undermined that it was necessary after 3 years to build an additional piece in the form of an "L" set against the old work on the two most exposed sides. After 3 years more, this in turn had to be sheathed on its two outer faces with 3-inch hardwood planking. When it is found to be impossible to maintain any structure beyond low-water mark, the best alternative is to sink a tide-well farther back, and to connect it with the sea by a siphon. This was done at Father Point.

Fig. 4.



SECTION OF SPECIAL INLET-ROSE.

On an open shore there is usually little danger of the inlet of the gauge becoming choked. If, however, the gauge is placed in a gully in the rock, or on the face of a cliff, the crib-work which is required to hold the lower end of the cylinder in position should be so set as not to interfere with the natural scour of the waves. If it is not judiciously placed, there is danger of its occasioning an accumulation of sand and gravel which will impede the inlet of the water, and may eventually choke it entirely. The observations on Anticosti Island came to an end in this way. The gauge-house there was set over a narrow gully in the rock, which ran in at right angles to the shore-line; and the crib-work, which held the lower end of the cylinder in place, was fitted into the gully, blocking it completely across. This crib-work lasted for four

seasons without repair, but in that time the heavy face-planking which was fitted to the rock became worn away by the drift of gravel against it. The gravel then worked into the interior of the crib, where it was held as in a trap, and eventually choked the inlet entirely. This would have been avoided if the cylinder had been held in the middle of the gully by open bracing, leaving the wash of storms unimpeded. When the choking occurred, the observations were discontinued, as tidal records had been secured continuously for 3 years, which proved sufficient at that station. A special form of inlet-fitting, used where gravel and sand accumulate, is shown in *Fig. 4.*

The tide-house which shelters the instrument must either be made sufficiently strong to resist the waves which may break over it, or it must be placed high enough to be out of their reach. The choice will depend on the amount of shelter or exposure. In one case, iron rods bolted to the rock were used as guys to hold the gauge-house in position, but it was found that the spray freezing on these accumulated in such masses of ice as to render them worse than useless.

In preparing and landing the material for the gauge, it is usually more convenient to build the tide-house in advance, as it is only 6 feet square and can be readily carried on deck. The iron cylinder forming the well can be floated ashore by fitting the open end with a wooden bulkhead. The only other heavy material is timber, which can be readily landed. The crib-work required is built in the ordinary way, of 12 inches by 12 inches timber, and is filled in with stone-ballast. The ballast has always been obtained in the locality, either from the rock or from small boulders on the beach. The iron cylinder, or its lower end, as the case may be, is held in place by the crib-work, and on the top of this the tide-house is set.

Heating and Ventilation.—Several mechanical devices for heating tide-gauges have been considered. The most suitable would probably be a circulation of hot water, but the difficulty in this case is to make the hot water circulate downwards below the source of heat. To use a force-pump would make the arrangements altogether too elaborate. In one case, where the gauge is in a harbour, steam-heating is used, which is of course satisfactory. In all the other tide-gauges, heating is afforded by oil-lamps burning a high-grade petroleum, having a flash-point above 120° F. To heat the tide-pipes, a cylindrical copper lamp, 9 inches in diameter, is suspended in the tide-well by a chain. This lamp is provided with three duplex burners with wicks

$1\frac{1}{8}$ inch wide, there being thus six wicks in all. The burners have copper chimneys to avoid breakage, with a small aperture covered with mica to see to regulate the flame. This has been found quite sufficient in the severest weather, as the amount of heating required is in reality not great. The top of the cylinder must, however, be made quite tight to exclude the outside air, while on the other hand some ventilation must be provided to supply sufficient air to keep the lamp burning. A proper method of ventilation is also important, to prevent damp from rising from the tide-well into the gauge-house. This ventilation is afforded by a 2-inch galvanized-iron pipe, led from the outer air to the bottom of the cylinder. A similar pipe, leading from the top of the cylinder to the open air, serves as an outlet for the fumes and damp air which would otherwise accumulate.

The gauge-house itself also requires heating. For this purpose any type of small oil-heater will serve, provided it has sufficient oil-capacity to burn throughout the night. The type adopted has two wicks, 4 inches in width. Above this heater is an inverted zinc funnel, opening into a 2-inch pipe which serves to carry off the fumes. Some air is admitted to the gauge-house by an opening of a few square inches in area, which can be regulated by a wooden slide. The ventilation above and below the floor of the gauge-house is thus distinct, this being of importance to preserve the instruments from damp air and the fumes of the lamps. The amount of petroleum used throughout the winter does not exceed 180 gallons at the coldest station, the usual consumption being 80 gallons to 120 gallons. This is the most economical fuel under the circumstances, as coal would have to be brought a great distance, and landed in boats on an open coast; and petroleum in barrels is much more readily handled. The best petroleum can be purchased in quantity for a little less than a shilling per gallon. With these arrangements, the heating of the gauges has gone on satisfactorily for several years. A fire occurred once, but before the high-grade petroleum referred to was used. The chief danger in this respect arises from the oil-heater in the gauge-house; and it is well to have this provided with a water-pan surrounding the wicks. The only other difficulty of consequence has been caused by the smoking of the lamps, the gauge-house becoming coated with a greasy and very penetrating soot, which may even find its way into the mechanism of the recording instrument, notwithstanding its glass case. This, however, can only result from deficiency of ventilation, or from carelessness. The only gauge which it has been attempted to run without heating, is at

Yarmouth, Nova Scotia, where the climate is milder than at any other of the gauge-stations, the average temperature during January and February being 26° F. The tide-column of this gauge is built of planking, and is not surrounded by an air-space. Several expedients have been used in the endeavour to prevent freezing in this column, such as a layer of thick oil on the surface of the water; but notwithstanding these, the record has been interrupted by frost for about a month or six weeks in the severest part of the winter.

For the regulation of the recording instrument itself, and its correct setting, there are two essentials, namely, time and height, as these are the co-ordinates to which the tide-curves are referred.

Correct Time for the Observations.—It is necessary for the tidal observations that the time should be correct within 1 minute. This, in any case, is as close as readings can be taken on the tide-diagram. At some of the tidal stations, as in cities, there is no serious difficulty in securing correct time. At others which are more isolated, but have telegraphic communication, arrangements were at first made for a time-signal each week or fortnight from one of the astronomical observatories. Although the distance was only some 400 miles, the rate charged for this signal was 8*s.*, as the line had to be cleared for the purpose and other business interrupted. At this rate the expense was considerable in the course of the year. Much greater satisfaction has been secured recently by the use of a meridian instrument or dipleidoscope, which gives excellent results. It consists essentially of two small mirrors like sextant-glasses, at an angle to each other, which give two images of the sun, and when the instrument is set truly in the meridian these images coincide at apparent noon. The most important advantage is that it does not require a skilled observer to use it when once it is set. The time at which the sun's images coincide can easily be observed within ½ minute by any man of ordinary intelligence. This gives "Apparent noon," and all that the observer has to do is to see that his watch shows the "Equation of time" at that moment. A practised observer who notes the first and last contacts of the images, as well as their central coincidence, and takes the average of these, can secure a time observation which can be depended upon within 2 seconds. The first setting of the instrument requires some skill, as either a chronometer or sextant observations are required for its adjustment in azimuth, and the instrument must also be set truly level by observing the reflection of a plumb-line in the mirrors. The instrument is

supported on an iron pillar, for which a cast-iron pipe 6 inches in diameter is very suitable; and it is protected from the weather by a light cover. It is important that this pillar be sunk in the ground below the depth reached by the frost, and to steady it securely it is well to make the excavation about 3 feet in diameter, to be afterwards filled in with cement. If this is well done, it will also keep the water from percolating through the ground and disturbing the pillar by freezing. Although thus carefully and solidly set, this has not prevented entirely the disturbance of such pillars; but, even when some small disturbance can be detected by close examination, the movement in azimuth is relatively much less than the vertical displacement, and it does not usually alter the dipleidoscope more than a fraction of a minute from the truth. It has been found best, however, to check its accuracy yearly or every other year.

Data for Height for the Observations.—For any tidal observations it is of course necessary to have a datum plane of reference, and it is also highly desirable if not essential that this datum should continue at the same elevation throughout the years of observation. Where a bench-mark exists to which the Admiralty low-water datum is referred, this has been made use of as the plane of reference for the tidal observations; but it is only in two harbours of Eastern Canada that such bench-marks exist, viz., Quebec and Halifax. At all the other tidal stations independent bench-marks have been established and a provisional datum-level has been adopted, until the tidal observations could be worked out. The bench-marks are necessarily independent or isolated, as no general system of levels yet exists in Canada; but they are serviceable in the meantime for reference locally. Where the natural rock was not of a durable character, the top of the iron pillar on which the dipleidoscope stands was used as a bench-mark. Much difficulty has been experienced in preventing vertical disturbance due to frost, notwithstanding the precautions taken in setting this pillar. It is well known that frost tends to raise any vertical pillar or post planted in the ground. The amount of this movement, however, is not great if the work is well done at first. The pillar of the dipleidoscope on St. Paul Island, where the best record has been kept, shows a rise of 0·06 foot in 4 years, as found from accurate instrumental levels from an auxiliary bench-mark cut on the face of the cliff. The rise occurred by the pillar slipping up through the cement, and in one winter it amounted to ¼ inch.

The limit of accuracy required in the elevation of bench-marks and in observations for height in general is 0·01 foot. As most

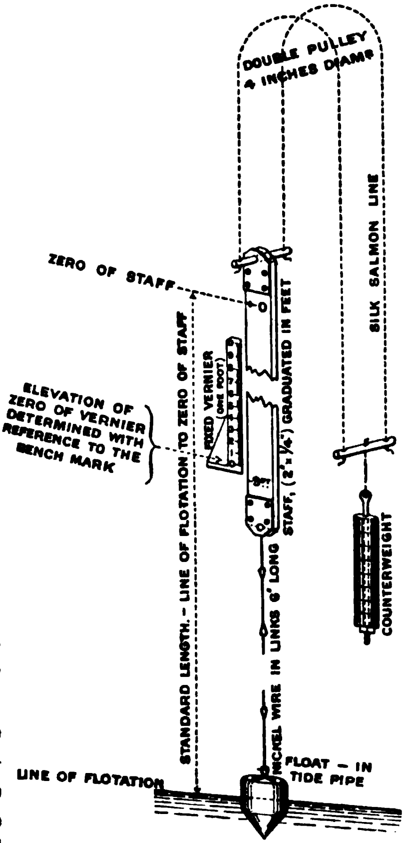
of the gauge-houses stand on timber-work, it may be mentioned that, in general, crib-work tends to settle and piling to rise. The settlement of crib-work is due either to the undermining action of the sea or to crushing, through decay. It is common to see crib-wharves brought up to their original level by building on top of them. On the other hand, wharves, built of piles braced together, work up out of the bottom by swaying.

At St. John, New Brunswick, where the extreme range of the tide is 30 feet, the best location to be found for the gauge was against a wharf built of crib-work. It was found, however, that this wharf floated up some 3 inches when the tide was high. The scale of feet attached to another part of the crib-work, and at first used for height readings, was also similarly affected; this occasioned much trouble until the reason was discovered. It was accordingly necessary to set the tide-column independently on the bottom, and to build the gauge-house on its upper end free of the wharf, in order to obtain a uniform datum-level for the observations. This tide-column was erected in 1894. It was built of timber, 3 feet square inside; and to reach bottom its total length had to be 55 feet. The lower end was filled with ballast to sink it, with the help of additional ballast-boxes on the outside: and 35 feet at the upper end remained open, to serve as the usual air-space around the tide-pipes. This open part was braced by inside frames to resist the water-pressure, and was thoroughly caulked With this arrangement the settlement only amounted to 0·02 foot in the 3 years 1896–1899, and 0·05 foot in the following 2 years up to the autumn of 1901. The greater part of the latter settlement occurred in this last year, while the upper part of the crib-wharf was being rebuilt behind the column, which was unavoidably swayed while held temporarily in position during these repairs. At Halifax the tide-column, with the gauge-house attached to its upper end, is set into a pile-wharf, but here also it stands on the bottom independently of the wharf. It sways with the pile-wharf itself, however, in stormy weather, or when vessels are moored to it; but the column has only risen in level 0·03 foot in the 4 years 1897–1901. In all such cases the only method admissible is to check the levels periodically by comparison with a bench-mark, and to make the necessary reductions for change of level in the calculations.

Sight-Gauge and Datum Plane.—At most of the tidal stations, especially those placed in exposed situations, it has been found impracticable to have an open scale of feet for reference, by which to keep the instrument set to correct height. Such a scale could

not be maintained on an open coast where there is winter ice; and, moreover, on account of the ocean swell, it would be very seldom indeed that satisfactory readings could be obtained. The plan of using a floating scale placed inside the gauge-house was therefore adopted from the outset. It is thus sheltered, and is affected only by the reduced motion in the tide-pipes; and readings can be obtained from it in almost any weather and at any season. The scale may be described as a graduated staff standing on a float, and rising and falling with the tide. The float is placed in a second tide-pipe alongside the other, in the column. As it is read by a fixed point or gnomon, the graduations on the staff are numbered consecutively from the top downwards. This may be termed a "sight-gauge," as full-scale readings are obtained directly from its face, just as they would be from a fixed scale of feet on which the water rises and falls. It will be readily understood that this gives the true height of the water above a datum plane which is represented by the level of the water when the staff reads zero. To define this datum plane, the elevation of the fixed reading-point or gnomon with reference to the bench-mark must be known; and also the total length of the sight-gauge, from

Fig. 5.



ARRANGEMENT OF SIGHT-GAUGE.

its zero to the water-line on the float which carries it. The general design of this sight-gauge, and the essential lengths and levels, are shown in *Fig. 5*, a vernier 1 foot in length being used to avoid the subdivision of each foot on the staff. The datum-plane given by the sight-gauge is the provisional or working datum. It should correspond with the zero-line of the tide-diagram on the

recording instrument, but it is by no means necessary that it should coincide with the low-water datum-plane finally adopted for the reduction of the observations. On the contrary, it is more convenient to have it 2 feet or 3 feet lower, to make sure that no tides will fall below the bottom of the tide-diagram, especially as the level of low-water at spring-tides is usually unknown at the beginning of the observations. When the final datum has been decided upon, after a sufficient length of tidal record has been secured, it can be ruled in as a horizontal red line on the face of the tide-diagram. By this method allowance can also be made for any changes in the working datum, which are very liable to occur, either from alteration in the elevation of the gnomon through settlement, or from change in the length of the sight-gauge. It is not necessary to detail the observations and reductions required to secure this result, as it is evidently possible to keep the red line, representing the final datum, at one constant elevation from year to year throughout the term of the observations.

The Sight-Gauge in Relation to the Range of the Tide.—Practically the accuracy requisite for the levels obtained from the sight-gauge varies inversely as the range of the tide. With a tide of small range the diagram has a large scale, and considerable accuracy is needed; but when the range is greater, and the scale of the diagrams is smaller, slight errors become inappreciable. This is in accord with the harmonic analysis itself, in which the limit of accuracy in the ordinates of the tide-curve should bear a constant ratio to its total amplitude to give equally trustworthy tidal constants. The two types of sight-gauge employed are designed to conform with this principle. When the range does not exceed 8 feet or 10 feet, the straight staff can be used, *Fig. 5*; but beyond this range the straight staff becomes too unwieldy, and a flexible scale is substituted, which can be doubled over a pulley-wheel. For this purpose a metal tape can be used. This modification is adopted at three of the tidal stations for a range of tide up to 30 feet. With this arrangement there is no doubt an inherent inaccuracy, as the weight of the tape overbalances on one side or the other as the tide rises and falls; but by averaging the individual readings the elevation of the final datum can be obtained as closely as it can be laid down on the fine scale of the diagrams of large range. A steel tape was first used for this type of gauge, but it rusted and broke frequently, and a ribbon of German silver was therefore substituted for it. A metal which will withstand the corroding action of sea-water cannot be graduated by etching in the usual way. It was accordingly necessary to mark the feet

only, by small punched holes designated by stamped figures, and to read the fractions of a foot by means of a fixed scale or vernier set against the edge of the ribbon. This ribbon is $\frac{3}{8}$ inch in width and its weight is 21½ ounces per 100 feet, or about twice the weight of an ordinary steel tape. The overfall on a range of 28 feet was found to change the position of the water-line on a 4-inch float by 0·14 foot, and half of this amount is the resulting variation from the true mean length, as measured at half-tide, from the water-line on the float to the zero of the tape at the other end. For this range of tide the vertical scale of the tide-curves is 1 inch = 4 feet, and on so small a scale any error in the position of the datum becomes quite inappreciable when this is deduced from the average of high and low readings. On the other hand, when the sight-gauge consists of a straight staff, the levels obtained are of a higher degree of accuracy, to accord with the larger scale of the tide diagrams, which may be as much as 1 inch = 1 foot. The staff is kept vertical by suspension from a pair of cords which pass over a double pulley and terminate in a counter-weight which balances the whole system. As the weight of these cords is inappreciable, there is no overbalance to allow for, as in the tape-gauge. The total length from the water-line on the float to the zero at the top of the staff must be accurately determined to the nearest $\frac{1}{8}$ inch. It is also highly desirable that the length should remain constant and unaltered, as any change in length alters the working datum of the observations. The distance from the lower end of the staff to the float is 6 feet to 24 feet, according to circumstances, and to make the necessary connection between these some kind of cord or wire is required which will not stretch or expand appreciably with the winter heating, and which will withstand corrosion from sea-water. For the longer lengths nickel wire has proved successful. It is made up into links 6 inches in length, to form a light chain, the links being so formed that they will not kink. When the distance between the staff and the float is not more than 6 feet or 8 feet, a wooden rod can be used for the connection. It is made of bass-wood for lightness, and it requires to be thoroughly varnished, because if it absorbs moisture it will depress the float and alter the effective length of the sight-gauge. To measure the length of the sight-gauge with sufficient accuracy, it is necessary to obtain the mark of the water-line on the float when the gauge is in complete working order. The best way to obtain this, is to polish the float with emery cloth and let it down carefully into the tide-pipe; the next day the water-line will be found distinctly marked.

The length can then be measured exactly with a steel tape. The main object to be kept in view is to enable the length of the sight-gauge to be determined and checked by a superintendent, and to have it so constructed that its length cannot alter between his periodical visits. The local observer is seldom competent to measure its length with accuracy in case it should require to be re-set; and any uncertainty in the length occasions much difficulty in the reduction of the results, and a residual uncertainty may remain which it may not be possible entirely to eliminate.

Wave Motion.—When an automatic tide-record is examined, two other undulations are found to occur, besides the main rise and fall of the tide. One of these has been termed "secondary undulation," which has a period of some 15 or 20 minutes, and has an amplitude varying between a few inches and 1 foot or more. In general, this secondary undulation is relatively more pronounced when the range of the tide is less. In the extreme case, where a tide becomes so flat as to be almost inappreciable, except at the spring-tides, the recording instrument shows these secondary undulations only, as all that is left. It is undoubtedly desirable to record these, as they are of much interest, and have given rise to some discussion, their cause being still largely unexplained. Some examples of these have been given elsewhere by the Author.[1]

The ordinary waves, on the other hand, it is desirable not to record on the gauge; but this is difficult to prevent. The only certain means of avoiding them is either to have the gauge in a thoroughly sheltered position, as in a harbour, or to have sufficient depth of water to enable the tide-pipes to extend below the limit of their influence. Where there is little shelter and no great depth, the most obvious method of reducing the motion is by extending the inlet of the tide-pipes along the bottom to deep water. At Father Point, where the gauge works by siphoning, an inlet-pipe, 2 inches or 3 inches in diameter and 420 feet in length, has a marked effect in preventing wave-motion, although the depth at the end is not great. The vertical movement communicated to the water in the tide-pipes has seldom exceeded 4 inches. This amount has occurred with a wind-velocity of 39 miles per hour from a direction in which the open exposure is 45 miles. The greatest difficulty in the way of a more extended use of this method is that a pipe lying on the bottom is sure to be disturbed

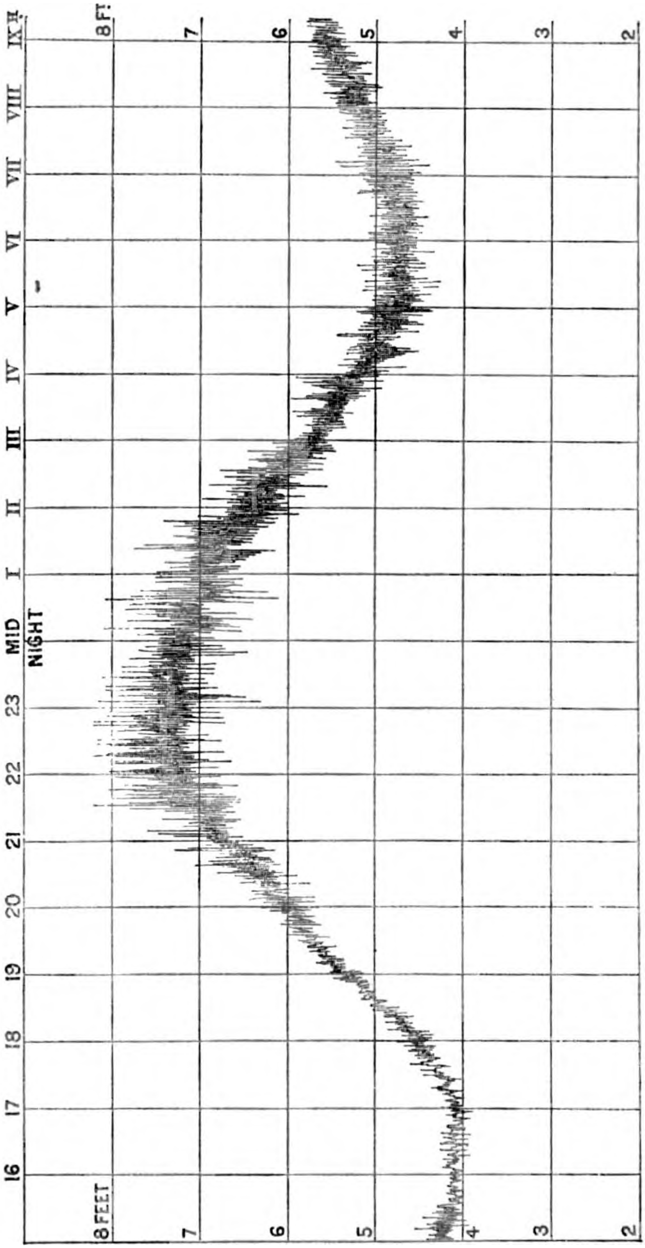
[1] Transactions of the Royal Society of Canada, second series, vol. i. p. 25, and vol. v. p. 23.

by storms and by ice. When this happens the pipes are bent or kinked at the joints, if these are flexible, and the gauge may become choked. This was the result of a trial of this method at St. Paul Island.

With regard to the selection of a site for the gauge, a comparatively shallow bay on a line of exposed coast will give efficient shelter in winter when ice forms, although it affords no shelter whatever, in the ordinary sense, in summer. But in winter the bend in the coast-line is sufficient to give considerable additional width to the shore ice; and although this may be broken on its landward edge by the rise and fall of the tide, it effectually prevents the waves from being felt in the bay. The water is thus kept perfectly still throughout the period of the winter storms; and, so far as the gauge is concerned, the heaviest weather at such stations occurs late in the autumn, before the ice forms. Some of the localities which are of most importance from a tidal point of view are practically without shelter, and devoid of any artificial works. It would thus be an expensive matter to reach any great depth of water. It is in such places that the range of the tide is only that of the open ocean, say 4 feet to 6 feet; and the amplitude of the swell frequently amounts to half the height of the tide itself, or even more. For this range of tide, the scale of the tide-diagram is 1 inch = 1 foot; and the tide-curve is often represented by a shaded band ½ inch or more in width, if the weather is at all rough, *Figs. 6* and *7*. The central line of this band is the true tide-curve. Even in these circumstances there is little uncertainty in the actual tide. The great advantage of a self-recording instrument, as compared with direct observations on an open scale of feet, is also obvious.

Except in cases where a considerable depth of water was available, no method has been found successful in entirely eliminating the effect of wave-motion; but some of the means adopted have been attended with a certain measure of success. The smaller waves, though sometimes as high as the wider swell, are more easily dealt with. Their motion is so rapid that its influence can be kept out of the tide-pipes by making the water pass through perforated strainers or devious passages, thus taking advantage of friction and momentum. A long heaving swell is more difficult to deal with, as the length of its period gives it time to find its way through into the tide-pipes with little diminution. At one point on the open coast of the Atlantic, where a summer station was erected and where the depth at low water was only 3½ feet, a small timber column was used. The inlet was at the bottom of

Fig. 6.

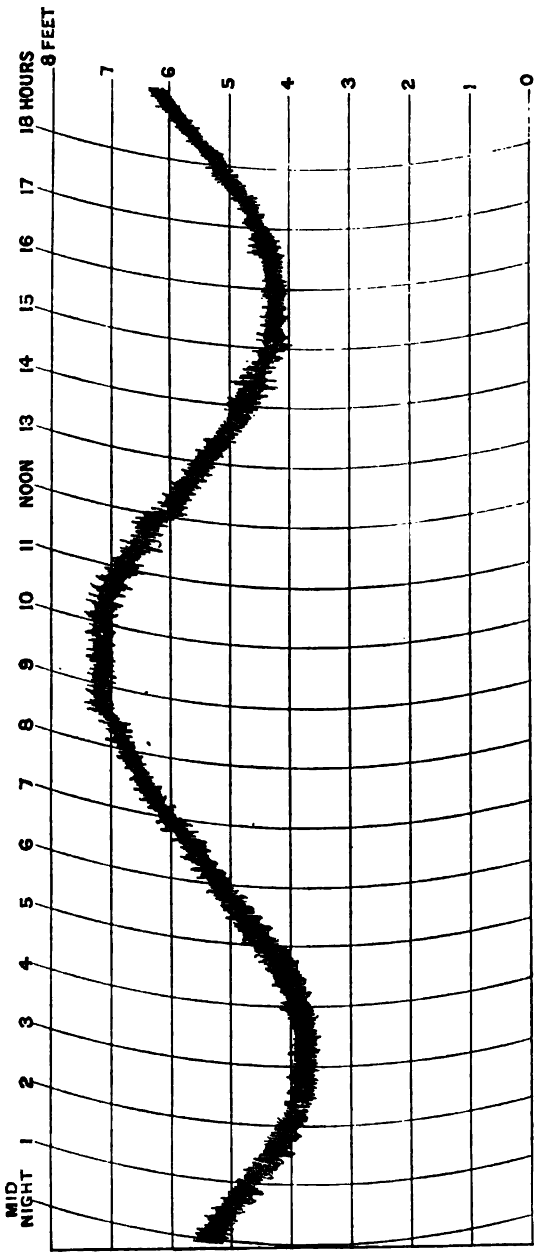


DISTURBED TIDE AND WAVE-MOTION, DURING STORM, 18-19 FEBRUARY, 1900, ST. PAUL ISLAND, CABOT STRAIT, CANADA.

the column. A length of 2 feet at its lower end was divided off, and in this space the water was made to pass up and down three times, as well as to pass through three sets of auger-holes in partitions, and narrow slits. Even by this means the long swell was not much reduced in the tide-column, but the smaller waves, with an amplitude of 0·60 foot, were diminished by 50 per cent. A diagram of the wave-motion at this station is shown in *Fig. 7.*

It has also been found with wooden tide-columns that the narrowest vertical cracks are sufficient to let through al-

Fig. 7.



most the whole of the wave-motion; but where the column itself is made water-tight by white-lead joints, and where the inlet is placed 6 feet or 8 feet below low-water level, the effect of ordinary waves is scarcely felt, unless the storm is so severe as to disturb the general water-level itself, as not infrequently happens. In this case, as the tide is exceptional in character, the margin of uncertainty in the true position of the tide-curve is of less consequence.

The Paper is accompanied by three photographs; and by six tracings and a map, from which the Figures in the text have been prepared.

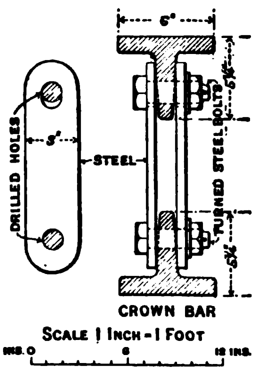
(*Paper No. 3315.*)

"Note on the Use of 'Serve' Steel Tubes in a High-Pressure Locomotive Boiler, and their Efficiency as Compared with that of Plain Iron Tubes."

By James Marchbanks, M. Inst. C.E.

In 1897 the Wellington and Manawatu Railway Company procured from the Baldwin Locomotive Works of Philadelphia a "Vauclain" four-cylinder compound consolidation locomotive, No. 16, fitted with "Serve" ribbed tubes. On the advice of the New York representative of the maker of the tubes, it was decided to employ tubes $2\frac{3}{4}$ inches in diameter, reduced to $2\frac{5}{8}$ inches in diameter at the firebox end, and enlarged to $2\frac{7}{8}$ inches in diameter at the smoke-box end. The tubes were of No. 9 gauge, and were 11 feet 6 inches in length between the tube-plates, 5 inches at the front end and 4 inches at the fire-box end being plain, and the remainder ribbed. A steel fire-box was fitted, having a tube-plate $\frac{1}{2}$ inch in thickness, the front tube-plate being also $\frac{1}{2}$ inch thick, and well stayed.

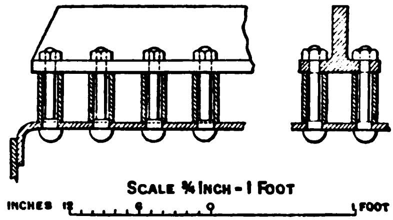
Figs. 1.



The crown-staying consisted of tee-bars, 6 inches by 1 inch in cross-section, set transversely across the box and slung from tee-bars riveted to the outside shell by four sling-stays, each consisting of a flat steel bar, 3 inches by $\frac{5}{8}$ inch in cross-section, having a hole at each end through which were passed $1\frac{1}{4}$-inch pins connecting the slings with the middle members of the tee bars; $\frac{1}{8}$ inch of slack was left in the top holes of the slings, *Figs. 1.* Button-headed stay-bolts, 1 inch in diameter and 4 inches pitch, secured the crown-sheet to the foot of the tee-bars. Between the crown-sheet and the tee-bars, which were 3 inches above the crown-sheets, these bolts passed through pieces of stout hydraulic

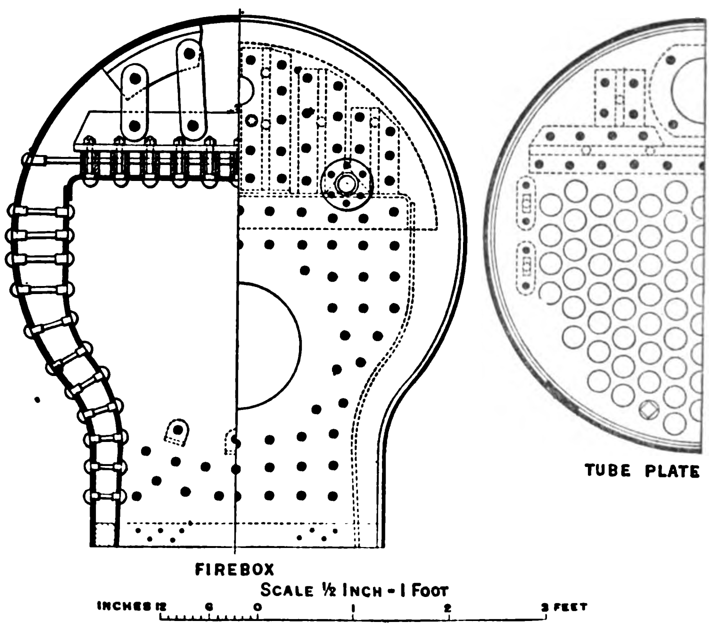
pipe, *Figs. 2.* It will be seen that, while the crown-sheet was well secured to withstand internal pressure, movement due to changes of temperature was not prevented. The arrangement of stays and the spacing of the tubes are shown in *Figs. 3.*

Figs. 2.



The engine was employed in hauling trains, of about 250 tons net, over a rough undulating section of line, 27 miles in length, the boiler-pressure being alternately raised to its maximum and then allowed to die down, as the various gradients were surmounted. The maximum gradients were:—northwards bound, 5 miles at a

Figs. 3.

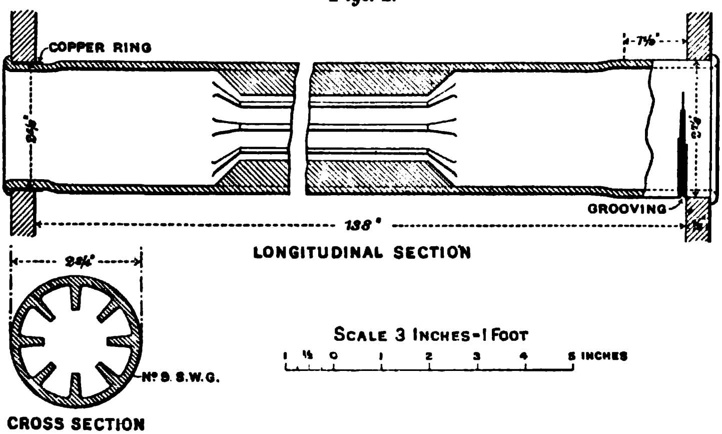


gradient of 1 in 40, and 3 miles at a gradient of 1 in 56; southwards bound, 3 miles and 5½ miles at a gradient of 1 in 56. An assistant engine was used on the 1 in 40 gradient. The conditions of service demanded that the engine should stand for about 2 hours

at the end of each 27 miles run. About 120 miles were run per day.

The water used was fairly pure, and every care was taken to keep the boiler clean, it being washed out at the end of every 7 days' service, after having been allowed to cool. From the time the engine was first put in service, a considerable amount of trouble was caused by flues leaking at the fire-box end. This was improved to some extent by keeping a clear fire and an even pressure of steam whilst running downhill, and when standing at the end of a run, but there was still a good deal of leakage. It was noticed that the leaking was much worse after cleaning fires, and as the boiler was fitted with rocking-grates, advantage was taken of this to clean the fire by rocking into the ash-pan. A

Figs. 4.



great improvement resulted, and it was found that, if care was taken to prevent large quantities of cold air from entering the fire-box, the tubes could be kept fairly tight. After about 6 months' service, odd tubes began to leak, necessitating the boiler-maker expanding some tubes on every wash-out day. Leakage also began to show at the smoke-box end, and on removing some of the tubes it was found that grooving had taken place close to the inside of the tube-plate, in some cases more than half-way round the tube, and almost through the metal, *Figs. 4.* This occurred chiefly in the two bottom rows of tubes, and extended about half-way round the boiler. These tubes were replaced by new ones, but the same effect continued to recur, and after 12 months' service the Author decided to remove the Serve tubes

altogether, and to substitute plain charcoal-iron tubes, 2 inches in diameter, of No. 12 B. and S. gauge. Since this was done the boiler has given very little trouble. The heat-absorbing surface of the Serve tubes, *i.e.*, the internal surface of the tubes in contact with the hot gases, was 1,235 square feet, and the heat-distributing surface, *i.e.*, the external surface of the tubes, was 745 square feet, and the total area for the passage of gases was 2·53 square feet.

In the plain tubes afterwards substituted, the total heat-absorbing surface was 860 square feet, and the total heat-distributing surface was 945 square feet, the flue area being 2·83 square feet.

The fire-box heating-surface was in each case 92·5 square feet, and the grate-area 17 square feet. The boiler steamed freely both with the Serve tubes and with the plain tubes, but after about 500 miles had been run it was noticeably duller when fitted with the Serve tubes. The Serve tubes were "run," on an average, about twice a week, and the plain tubes once a week. The smoke-box was fitted with a deflector-plate in front of the tubes, which caused the sparks lodging in the smoke-box to be swept well forward; these were blown out when necessary by means of a spark-ejector. The smoke-box door was not opened except to run the tubes. With regard to the relative efficiency of the Serve and plain tubes, the engine, when fitted with Serve tubes, consumed, on an average, 55·4 lbs. of coal per mile, while during the 6 months after the Serve tubes were removed the consumption was 55·2 lbs. of coal per mile, and for the following year 56 lbs. per mile, or 0·272 lb. per net ton-mile. From this it appears that the 860 square feet of heat-absorbing surface of the plain tubes was as efficient as the 1,235 square feet of heat-absorbing surface of the Serve tubes, or the heat-absorbing surface of the Serve tubes has 69·6 per cent. of the efficiency of that of the plain tubes. The Author is of opinion that, owing to leaky flues, the coal-consumption was greater with the Serve tubes than it otherwise would have been.

No separate account was kept of the cost of boiler-work, but the following are particulars of the cost of all repairs on this engine:—

	Per Mile.	
For 6 months ending February, 1898 . . .	1·70*d.*	Boiler fitted with Serve tubes.
" 12 " " " 1899 . . .	3·6*d.*	" "
" 12 " " " 1900 . . .	3·2*d.*	Serve tubes removed, plain tubes substituted.
" 12 " " " 1901 . . .	1·60*d.*	Boiler fitted with plain tubes.

It will be seen that for the 12 months before the Serve tubes were taken out the cost of repairs was 3·6*d.* per mile; for the first year the plain tubes were in service the cost was 3·2*d.* per mile (this included the cost of fitting the plain tubes); and for the last 12 months the cost was 1·6*d.* per mile.

The coal consumed on a compound engine of the same class, No. 13, and on the same run, might be mentioned. This engine carries steam at a pressure of 180 lbs. per square inch, has 959·4 square feet of tube heating-surface, 92·6 square feet of fire-box heating-surface, and 17 square feet of grate-area. The tubes, of charcoal-iron, are 2 inches in diameter externally, and the boiler is stayed radially, the load hauled being about 14 tons less than with engine No. 16. The coal-consumption for the past 2 years was 56·43 lbs. per mile and 55·92 lbs. per mile respectively, and the consumption per net ton-mile was 0·299 lb.

In conclusion, the Author is of opinion that the failure of the Serve tubes by grooving was caused by the ribbed portion being so rigid that all vibrations were concentrated at the front end, which is the thinnest and weakest part of the tubes, and that if, instead of the internal diameter of the tube being increased where it passes through the front tube-plate, it were kept parallel and the thickness of the metal back to the ribbed portion increased, better results would be obtained.

The Paper is accompanied by three photographs of drawings, from which the Figures in the text have been prepared.

(*Paper No. 3304.*)

"The Present Position of Electric Traction on Tramways and Roads, with special reference to Accumulator Traction."

By William Ranson Cooper, M.A., B.Sc., Assoc. M. Inst. C.E.

The following Paper is devoted to a general comparison of the various systems of electric traction at present in use on tramways, and to a consideration of the possibilities of electric automobilism.

The Overhead-Trolley System.

The direct-current single-trolley system of electric traction for tramways, although still lacking adequate development in the United Kingdom, can claim, at the present time, many thousands of miles of track in different parts of the world. This success is doubtless largely due to the simplicity of the system, coupled with its comparatively low cost, but it is also contributed to by many subsidiary factors, one of the chief of these being the series-wound motor, which has the valuable property of providing a powerful starting-torque. As the field-coils carry the main current in series with the armature, the torque is, within certain limits, proportional to the square of the current; and, consequently, electric cars equipped with series-motors are able to attain their maximum speed much more rapidly than is possible by other means of locomotion. There is another property of the series-motor which is in some respects an advantage and in others a disadvantage, namely, the variation in speed. At light loads the speed is high, whilst at heavy loads, on account of the great increase in the strength of the field, the speed is low. Consequently a car equipped with series-motors travels more slowly on an up-gradient than on the level, if the motor is working under the same conditions. The tractive

force is developed where required, but it is done at the expense of speed. This is often exactly what is desired, because less energy is required for a given trip if it is permissible to run at low speeds under a heavy load, and the capacity of the power-station is thereby increased, because a larger number of cars can be run by a given plant than is the case if the cars are run uniformly at the same rate under all conditions. In other respects, however, this is a disadvantage, because from the point of view of dealing with traffic the speed should be uniform. This is more particularly the case when the traffic becomes heavy, for example on certain holidays. Under heavy traffic the series-motor slows down, rendering it difficult to keep to schedule time, and thus increases the difficulty of dealing with the traffic when it exceeds the normal.

In the case of the shunt-wound motor, however, the speed does not vary with the load to anything like the same extent, because, in general, the field is practically constant; but such a motor has the disadvantage that the starting-torque is much smaller. Since the field is constant, the torque varies directly as the current in the armature, and therefore varies much less than in the series-motor. For this reason the shunt-motor was discarded in electric traction. It is, however, often noticeable in the development of an industry that what is regarded as unsuitable at an early stage is again taken up later on, and found to be really what is required for certain purposes. It is an open question whether the shunt-motor is not preferable to the series-motor for certain kinds of traction-work, notwithstanding the early verdict to the contrary. A few engineers have moved in this direction. For example, Mr. Thomas Parker found that an accumulator road-carriage, when equipped with a series-motor, required a heavy starting-current and varied considerably in speed according to the gradient. On re-winding the motor with a shunt, he found that the carriage moved steadily away at starting and maintained a very constant speed on all gradients. It was in every respect satisfactory, and moreover the motor was able to return energy into the cells on a down-gradient. No doubt, if high acceleration is required at starting, the shunt-motor does not give sufficient torque; under such circumstances it might be worth while to make use of a compound winding, so arranged that the series coils are automatically cut out when the controller has moved over the first few notches.

The most serious difficulty with which the trolley system has to contend at the present time is that of electrolysis. It is all the

more serious because the evil cannot well be detected, and is generally disregarded until the damage is beyond repair. An electric current will never prefer one of two alternative paths, to the complete exclusion of the other; and therefore it follows that however good a conductor the rails of a tramway may be made, by bonding or by supplementary conductors, a certain proportion of the current will return through the earth. The proportion so returning will depend, of course, upon the configuration of the line and upon the quality of the soil, and will vary from day to day according as the soil is wet or dry. Where these earth-currents meet a metallic conductor, such as a water-main or a gas-main, they are likely to make use of it, and corrosion will take place wherever the current leaves such a pipe. Under certain conditions it is possible for a current to leave at the end of one pipe and return at the beginning of the next pipe, at every joint of a pipe-line, if the joints are of high resistance, thus causing corrosion in every pipe. In America, where electric traction is not regulated by rules like those of the Board of Trade, a very great deal of harm has been done by electrolysis. It is found that lead pipes are the most readily attacked. Wrought iron is affected to a less extent, and cast iron, which is used more than any other metal for these purposes, is fortunately attacked still less. So far, protective coatings have been found to be of very little value, and even if a suitable substance were found it would afford no protection to pipes which are already laid. If pipes were attacked uniformly, the danger would be less serious; but as the oxidised surface of a pipe and the surrounding soil vary in conductivity from point to point, the corrosion generally takes the form of pitting, and consequently the pipe becomes eaten through at a few points where the current is concentrated, while it is still sound over the greater part of its surface. There is one condition under which serious electrolysis does not take place, viz., when the current tends to set up a back electromotive force greater than the potential difference between the points considered. It is on this basis that the regulations of the Board of Trade for the prevention of electrolysis by earth-returns were drawn up. In these regulations it is provided that a pressure greater than 1·5 volt between a pipe and the return, tending to give a current towards the latter, shall not be allowed.

This is approximately the pressure required for the ready decomposition of acidulated water, and is sometimes referred to as the "limiting pressure" required for the electrolysis of water; but

in the case of many saline solutions the limiting pressure is much smaller. It has, indeed, become a recognized fact that electrolysis does not, as a rule, cease when the applied potential difference falls below a certain limiting value, although it may become very small. Under certain conditions, such, for example, as are found in the copper voltameter, the current increases simply in proportion to the applied difference of potential. It therefore follows that the Board of Trade regulations are not a complete protection. From experiments upon this subject, Dr. Fleming[1] has concluded that electrolysis will take place with pressures amounting to only a small fraction of a volt. The danger arising from electrolysis may be said to be relative in its character. All water-pipes have a natural term of existence, and therefore there can be no objection to electrolysis taking place so long as the depreciation of pipe-systems is not materially increased. It would be a useless refinement to reduce electrolysis below such a limit. On the other hand no good can come of ignoring the fact that harmful electrolysis may be possible under the regulations of the Board of Trade. On short lengths of line these regulations would probably be a sufficient safeguard, for the extent to which harm may be done depends upon the size of the network. There are several ways in which electrolysis may be more or less avoided: for example, by a three-wire system; by alternating currents; by insulated return, either by trolley-wire or conduit; by a surface-contact system; or by accumulators. The three-wire system for traction, making the rail the neutral conductor, has not come into favour owing to the difficulty in maintaining a balance. It is, however, now in use on the City and South London Railway. The use of alternating currents would not prevent electrolysis, but would cause the corrosion at any point to be diminished, because it could only take place during half of each alternation, and for the same reason the corrosion would be very much more distributed. The only absolute cure seems to be by the use of accumulators, or by means of an insulated return, either as a double-trolley system, or by a conduit. The objection to the two last-mentioned is the same, viz., expense and complication; but such an objection applies much more strongly to the conduit- than to the trolley-system. The double-trolley system is in use on 220 miles of track in Cincinnati, with apparently satisfactory results, and by recent Acts of Congress this system is now compulsory on all new

[1] Paper read before the British Association, 1898.

lines or extensions in the district of Columbia. A surface-contact system might be found to be only a partial cure, on a large network, owing to the excessive leakage which takes place during bad weather. By the use of accumulator-cars electrolysis is, of course, completely eliminated.

Conduit Systems.

The trolley system is characterized by cheapness and simplicity, and therefore any alternative system must be considered from the points of view of relative cost (both as to capital and maintenance) and ease of working. The conduit system is much more expensive than the trolley system in capital cost, for it is necessary that the conduit be made strong enough to support the heaviest traffic and to prevent closing of the slot; it must also be properly drained, and provided with suitable man-holes. Mr. A. N. Connett estimates the difference in cost between a trolley- and a conduit-line to be £7,000 to £9,000 per mile of single track under ordinary conditions, the cost varying according to the sub-surface obstructions and the amount of special track-work. This applies to the construction of new lines. If it is a question of converting a line from horse- to electric-traction, and the track is sufficiently heavy for electric working, the extra cost of introducing a conduit will, of course, be much higher than that above-mentioned, and a trolley system would be much cheaper. With regard to maintenance, according to Mr. Connett the extra cost of running the conduit-line in Brussels, as compared with the trolley-line, is 0·31*d.* per car-mile. The cost of cleaning the conduit at Washington amounts to £5 10*s.* per mile per annum, four or five men being sufficient to clean 1 mile of conduit in a day. The expression of cost in terms of the car-mile is rather unsatisfactory in a case of this kind, where a large portion of the cost is independent of the number of car-miles run, for the cost per car-mile must necessarily vary very much with the total car-mileage. In addition to the cost of maintenance, there is the question of depreciation and renewal of the whole system, with regard to which information is lacking at the present time. The capital outlay being heavy, this matter is of considerable importance.

Conduit systems are working successfully at Washington, Buda-Pesth, and elsewhere; but success depends to a large extent upon climate and local conditions. For example, severe winters

would be likely to give trouble. In the case of the Blackpool tramways, sand was found to be very troublesome. On account of such disadvantages, the conduit system is likely to be introduced only where the use of the trolley is prohibited by the Authorities. This is the case in parts of Paris, where a conduit system has been recently laid down under very stringent conditions. A central slot was not allowed, on account of the additional obstruction to traffic caused by wearing away of the wood pavement, and therefore it became necessary to use a side slot. This form of construction, when compared with the central slot, has the advantage that it is cheaper to the extent of about £500 per mile of single track, but it is objectionable from several other points of view. For example, the conduit has to be stronger, because it carries the car-traffic as well as the ordinary road-traffic; the insulation of the plough is more difficult to maintain on account of being splashed with mud by the wheels of the car; there is also great difficulty in making satisfactory rail-switches with a side slot, and in the case of double track the relative position of slot and car changes when the car passes from one track to the other, if the conduit is placed under the two inner rails; thus the position of the plough requires to be changed. In Paris, to avoid the two last-mentioned difficulties, a central slot is used where points are necessary, the side slot being used on other parts of the line, and the plough is made to slide automatically from the side to the centre before the points are reached, the switch for the slot being reached sooner than those of the track. This requires special construction on the car, in order to allow the necessary freedom. As the plough is always carried on the car, provision has to be made for raising it; and gear, which may be set in operation when the central slot is in use, is provided for this purpose. At the junction of the trolley and conduit systems the slot is opened when required by the raising of two cast-steel covers, to allow the plough to be withdrawn. When the mechanism for raising the plough is brought into action it operates a commutator which makes the changes required in the circuits in passing from the conduit to the trolley system.

The chief objection to the conduit system, electrically, is that so much of it is hidden and cannot readily be reached. Defects are not easily discovered until they become serious, and conductors are not readily replaced. Other electrical difficulties, such as leakage from flooding, do not occur if the conduit is large enough and properly drained. A large conduit, however, not only increases

the cost on account of material, labour, etc., but is also liable to increase considerably the cost of laying, through interfering with existing gas- and water-pipes along the route. It follows, therefore, that the objection to conduit systems is chiefly financial, and that their application must necessarily be limited to routes where the traffic is heavy. There is a certain risk which is always entailed in heavy capital expenditure, namely, that the system installed may be superseded by some other system requiring a much smaller capital, and possibly as economical in working. A possible rival of this kind to tramway traction is the motor-omnibus, which may prove a serious competitor in the future, when the motor-car industry is more advanced than at present. A saving of capital varying, say, between £5,000 and £20,000 per mile of route will permit a comparatively heavy cost of running per car-mile without giving an unsatisfactory financial result, notwithstanding the smaller capacity of an omnibus as compared with that of a tram-car.

Surface-Contact Systems.

In the case of surface-contact systems the chief difficulty is not merely financial, but also electrical. The capital cost is intermediate between that of a conduit and that of the trolley system, and therefore is not necessarily serious. The excavation required is less, and only at intervals to any considerable depth; consequently trouble arising from pipes, which would form obstructions to the laying of a conduit, is to a great extent avoidable. The renewal of parts is also a simpler matter in a contact system. But although the capital cost may be comparatively low, the cost of maintenance is liable to be very heavy, and it may be said that, from the purely financial point of view, a surface-contact system is not likely to be commercially successful unless the cost of maintenance can be reduced to a reasonably low figure. Perhaps the greatest difficulty, however, is the possible danger from shock if a stud happens to remain "alive" after the car has passed, and it is probably this danger which is responsible for the very small extent to which such systems have been tried. A trailing contact is sometimes used to short-circuit any stud which accidentally remains alive and to render it dead by blowing a fuse; but this method is not altogether satisfactory, because fuses may be blown unnecessarily and injurious arcs may be formed if the mechanism is sluggish. Another objection is due

to the large number of moving parts. The natural tendency in engineering is to avoid automatic moving mechanism as far as possible, in order to secure freedom from breakdown, and thus the tramway engineer might be expected to be prejudiced against a contact system as compared with the trolley system. A third objection is on account of leakage. This is liable to be excessive in wet weather, especially if there is much horse-traffic and the roads are not well cleaned; and it may at times seriously increase the load on the station if precautions are not adopted, although the average loss throughout the year would probably amount to only 2 per cent., according to experiments by Mr. Miles Walker. The most severe conditions probably arise when the track is covered with snow, and salt is sprinkled upon it to cause liquefaction, as is customary in many towns. The line then becomes covered with such a good electrolyte that what amounts almost to a short circuit occurs wherever a car is running. Under these conditions, if the fuses are light enough to blow, traffic cannot be continued; and if they do not blow, the stud-mechanism may have to break a much larger current than it is designed to break, with the result that a destructive arc is formed, which maintains the contact alive as long as it continues, and may thus prove a source of danger to the public.

There are but few examples of the commercial application of surface-contact systems over any considerable length of line. The Diatto system appears to have reached a greater mileage than any other, and purely on that account, apart from the question of comparative merits or demerits, a description of it here may not be out of place. This system has been adopted for 7½ miles of line at Tours, for 6¼ miles at Lorient, and by four tramway companies at Paris to the extent of 62½ miles, or a total length of 76¼ miles of single track; of this length 2½ miles, 6¼ miles, and 35 miles respectively are now (February 1901) in operation in these three towns, or a total of 43¾ miles. The results obtained from so considerable a scale of working should be of the greatest value. The Diatto system depends essentially upon the attraction of an iron plunger beneath the stud by a series of electro-magnets carried by the skate on the car. These electro-magnets are normally excited by the motor-current, but at starting current is furnished by a battery of accumulators on the car. A section of the contact mechanism is shown in Fig. 1, Plate 6. The plunger K moves in a bath of mercury contained in the tube J, of ambroin. This mercury is in contact with the supply-cable Q by means of the copper plug

P, which is in metallic connection with a second mercury-bath contained in the socket O, which forms the terminal of the cable. The tube R is also of ambroin. Thus when the plunger is in the position shown in the diagram it is alive, but is insulated from the stud C by the ambroin J. The stud is of soft steel supported by a ring A of nickel-steel, and has attached to its lower surface a carbon contact G. The head of the plunger carries a corresponding carbon contact H. Thus when the skate comes over the stud the electro-magnets attract the plunger upwards, the necessary contact is made between G and H, and the stud becomes alive. The skate consists of two soft steel bars 19 feet 9 inches in length, the centre bar being broader than those on either side (Figs. 2, Plate 6). These bars are carried by double electro-magnets E, which are spaced at intervals of about 4 feet, and have three poles, in contact with the three bars. The outer poles are rigidly attached to the outer bars, which do not make the contact; but the centre pole carries a laminated bar L of eight plates each 0·08 inch in thickness, which in turn are fixed at their extremities to the centre bar, thus giving the necessary play. The electro-magnets are so wound that the outer poles are of opposite polarity to the centre pole. The cross-section of a line, and the position of the skate and electro-magnets, are shown in Fig. 3, Plate 6. The centre bar is the only one which makes contact, the other two merely serving to direct the magnetic flux. Wings of cast iron, M M (Fig. 1, Plate 6), carrying a ring N, are included in every stud-mechanism, to improve the magnetic circuit between the outer and central magnets. These wings appear to be of real utility, for experiments show that the number of ampere-turns required for raising the plunger without them is nearly three times the number necessary when they are in use. The cost of installing this system on one of the lines in Paris, excluding feeders and paving, was £3,200 per mile of single track, and the charge for maintenance was £128 per mile per annum. There were certain local causes, however, which made the capital cost higher than it would otherwise have been. The Author was informed by Mr. Macloskie, chief engineer of the syndicate which contracts for the Diatto system, that the insulation in good weather is 300,000 ohms per mile, falling to 125,000 ohms in bad weather. The usual leakage from a live stud in wet weather is 0·1 ampere, but under exceptional conditions, with salt on the ground, the leakage has risen to 60 amperes or 70 amperes. A considerable portion of the cost of maintenance is due to the

renewal of the asphalt round the studs. As a substitute for asphalt the Company is now experimenting with glass. This glass, which is grey in colour and is very tough, is the refuse at glass-works, which has been heated to a very high temperature and has then been tempered. A kilometre ($\frac{5}{8}$ mile) of single track so equipped has given satisfactory results for some months, the repairs being very slight and confined to the paving. This material has the good quality that if a block is not properly tempered it falls to pieces at the first chip, and thus danger from such a cause is soon discovered. If these glass blocks are really found to be as suitable as they appear to be, the Company expect to have no difficulty in reducing the cost of maintenance to £115 per annum per mile of single track. At the present time, for 43$\frac{3}{4}$ miles of track in Paris, eighteen men are required. Some trouble was originally caused by the daily warming and cooling of the ambroin cases, air being forced out through joints on warming, and moisture being drawn in from the outside on cooling. A continuation of this process gradually affected the insulation to such an extent that the contact finally became alive. This difficulty was overcome by making the cases air-tight, the main joint being made with rubber, as shown at L in Fig. 1, Plate 6. All contact-boxes are now tested before being used, to see that they are air-tight. Mr. Le Blanc, late chief engineer of the Compagnie Générale de Traction, informed the Author that the particular line in Paris under his control worked satisfactorily under ordinary conditions, giving no trouble from leakage or live contacts. In the winter of 1900–1901, however, the conditions during snow-storms were unusually severe, on account of the sprinkling of salt on the streets by the City authorities. The presence of such a good electrolyte on the track caused practically a short circuit and a very heavy current at any point where a car was running. The contact-mechanism is, of course, not intended to break any considerable current, this being done at the stud. It will break a current of 10 amperes or 12 amperes, but it cannot deal with such a leakage as 60 amperes or 70 amperes; consequently when such a leakage occurs an arc is formed, the stud remains alive and the mechanism is damaged. Experiments have been made with a mechanism having two breaks in series, but this arrangement did not work well with such heavy currents. On account of leakage the use of salt was liable to cause the whole system to shut down, and when once salt has been used it is difficult to remove it, especially in wood-paving,

where it can soak in and continue to be a source of danger whenever there is rain, until it is washed out. With alternate wet and dry weather, crystallization and creeping take place, not merely about the stud, but also finally about the ambroin case, with the result that leakage takes place inside the stud-pit as well as on the surface, and can be cured entirely only by replacing the mechanism. Another cause of weakness was the stipulation by the City engineers that the street paving of the boxes should be supported by girders at a short distance from the live parts. This distance was so small that the possibility of a short circuit with snow and salt on the track was much increased. Several horses were killed through studs remaining alive during times of snow, but since the Company have been permitted to clear the snow themselves such accidents have not occurred. There appears to be an inherent difficulty in surface-contact systems in working under bad climatic conditions. When roads are dry, or even when they are wet, so long as the water is what may be called clean, there are no doubt many surface-contact systems which will work satisfactorily. But when the water has matter in solution so that a car is practically shunted by a short circuit, the mechanism of a system may become deranged and the demands upon the power-station become excessive. As a safe-guard against live studs, a trailing short-circuit was at one time used on the Diatto system, a fuse being blown if a stud remained alive. The fuse was placed in the lower part of the apparatus, and was so arranged that, in blowing, the cable was forced out. The mechanism then became entirely disconnected; but the cable was liable to be earthed at the side or bottom of the pit, and the surrounding ground made alive. A further disadvantage was that the fuse was liable to be blown on account of slight sluggishness of the plunger, and studs were put out of action in this way although not defective. Moreover, the plunger sometimes fell at the moment when the fuse was on the point of blowing, with the result that a very heavy current was broken at the contact, and the mechanism was damaged, or even blown to pieces, by the arc so formed. No safety-device is now used, but a trailing contact is occasionally attached, at a greater distance from the skate than was previously the case, and an inspector, equipped with a telephone in circuit with this trailing contact and with earth, travels on the car. If a stud is alive, or even if the insulation is defective, a click is heard in the telephone. A practical disadvantage in the Diatto system, as also in all others of the same kind, is the carriage of an

auxiliary battery on the car. Such batteries add to the cost of equipment, and unless they receive careful attention they are apt to deteriorate rapidly, because they form an unimportant subsidiary part of the equipment and are more or less out of sight.

Accumulator Traction.

Electric traction by means of secondary batteries carried on the car is theoretically an ideal system. The trolley-line, which by many is considered unsightly, is eliminated, and a saving is effected in capital cost, not merely in the overhead line and in the bonding, but also by the elimination of feeders. Against this must be set the outlay upon batteries. In considering the question of capital, it must be remembered that the capital absorbed by the trolley on a given track is independent of the number of the cars, although the maintenance-expenditure depends upon the number of car-miles. This statement is, of course, only true in a general sense, because the cost of feeders increases with the traffic, and the cost of maintenance is not strictly in proportion to the number of car-miles. In the case of batteries, on the other hand, the initial cost is proportional to the number of cars, although the maintenance expenditure again depends upon the number of car-miles. It therefore follows that accumulator traction will appear in the best comparative light on lines having a low car-mileage per mile of route. If the line is short and the traffic heavy, batteries cannot effect a saving of capital as compared with the trolley system, and, moreover, the maintenance per car-mile is heavy. But there still remains the possibility of a saving in capital in the power-station, because, with suitable management, the generators may be run at constant load; they may therefore be smaller and may be run more economically. Varying load due to the starting of cars is absent. On lines worked simply by accumulators (at least when charging is effected at constant current), and also on lines worked on the mixed system, the constancy of the load is very noticeable, whereas the plant in ordinary tramway-stations has to meet a rapidly varying load, in which the minima and maxima are in the ratio of about 1 to 3. It must, however, be borne in mind that the disturbing effect on the load, caused by the starting of cars, depends upon the number of cars in operation. On a large system such an effect becomes less noticeable, because the cause is continually in action and the percentage variation is smaller; and

this variation may be still further reduced by the use of a buffer battery. But in any case, unless batteries are used, the variations are very considerable and the plant is working under conditions that are far from economical. There is one advantage which is possessed by accumulator-traction alone, and which is due to the fact that each car, in a way, works independently of the power-station. Consequently, an interruption of supply in the station does not necessarily mean an interruption of the traffic over the whole system.

The conditions under which accumulator traction has been attempted have often been most unfortunate. When other systems of electric traction are for various reasons inadmissible, accumulators are resorted to as a last resource, often, it would seem, without any consideration of the conditions which must be fulfilled if the result is to be successful. A few years ago the Author saw a very good example of this kind at Nice, where an accumulator-line was run to Cimiez, a distance of 2½ miles. Cimiez is on very much higher ground than Nice, and the line is on a severe gradient for nearly the whole distance. Light cars for thirty-four passengers were used, of the open-type frequently seen on the Continent, and were equipped with two 20-HP. motors and ninety Laurent-Cély cells of 150 ampere-hours capacity. The gradient itself imposed a task which the cells could not be expected to survive for any length of time, and this was rendered still more severe by overcrowding the cars to the utmost extent in a way which would not be permitted in this country. It is not surprising, therefore, that this line added one more to the so-called failures of accumulator-traction. Another instance of unsuitable conditions is to be found at Berlin, where there is a line 12½ miles in length worked on the mixed system. The trolley part of this line is too short in comparison with the remainder to allow the cells to be completely charged during the time when the trolley is in use, and therefore satisfactory working is impossible. There are so many factors entering into the successful working of an accumulator-line that the most careful design is necessary. Even after many failures it does not seem to have been sufficiently recognised that the accumulator is the weakest point in the whole system, and that, consequently, the car must be designed for the battery rather than the battery for the car. In the Birmingham line, for instance, which has been the one example of accumulator tramway-traction in this country, and a most unfortunate one, many of the cars when built were never intended for accumulator

traction, but were adapted, and they appear to have been run under conditions which were certain to lead to failure. The conversion of this line to the trolley system does not, however, appear to be due to any failure of the accumulators.

Owing to the special training which is necessary for the successful handling of accumulators under all conditions, it is preferable to separate completely the management of the accumulators from that of the remaining plant of a tramway, the former being placed in the hands of the makers, who receive a fixed sum per car-mile for the complete maintenance of the batteries. This appears to be the general method followed on the Continent, and has given satisfaction. One of the chief objects which engineers have had in view is the reduction of weight of the battery to a minimum, with the result that both capacity and mechanical strength are sometimes too low to permit of a satisfactory life. Rapid charging may also considerably reduce the life. A case of this kind was brought to the notice of the Author when on a visit to Paris in the summer of 1900. The line in question was equipped with double-deck cars carrying fifty-two passengers, and weighing, empty, about 16 tons. Of this weight the battery of two hundred cells accounted for 5 tons, certainly a sufficient weight. The cells were fixed under the seats, and were charged in position. The method adopted was to charge the battery slowly at night, but during the day to make use of rapid charging, a charge of 12 minutes duration being given at the suburban end of the line after every journey. The capacity of the cells, notwithstanding their considerable weight, appeared to be too low for the work which was required of them, and consequently the pressure was abnormally low at the end of a journey, the result being that when a battery was switched on to the charging-circuit the initial current rose to 400 amperes. This current, of course, fell somewhat rapidly, but the passage of so large a current through the battery caused considerable heating, and the evolution of a great deal of gas. Ventilation of the cells was effected normally by means of a fan driven electrically, but so much explosive gas was evolved that it was liable to be ignited by the sparking at the commutator of the fan-motor, and to avoid explosion it was found necessary to remove the seats during the period of charging. When the Author visited this line the seats were always removed in this way, and, as may be well imagined, the atmosphere in the car was unbearable, and must have had a bad effect upon the car-body. It is scarcely necessary to state that under these conditions the

deterioration of the batteries was extremely rapid. Length of life and lightness in a battery are both very desirable qualities, but unfortunately they are conflicting. The cost of maintenance is diminished if the weight is increased, but the cost of traction is increased by the dead weight. Thus, if the cost of a new battery is comparatively low, it may be better economy to have a light battery with a short life rather than a heavy battery with lower expenditure in maintenance. But as the extra cost of transporting a heavier battery is only that of the extra energy, varying between 80 watt-hours and 130 watt-hours per ton-mile, it follows that the extra maintenance-cost of a light battery may easily exceed the extra cost of transporting a heavier one.

The problem of accumulator traction is complicated by electrochemical as well as mechanical difficulties, and it is possible that the former are the more important. Vibration, for example, has been regarded as one of the most serious evils, and perhaps more importance has been attached to it than it deserves. The most serious defect of lead cells is probably the loss of capacity which results from over-discharge. If that is the main difficulty, then a battery should be large for the work which it has to do, and only a fraction of its capacity should be made use of: *i.e.*, it should never be discharged to the ordinary limit, and it should be frequently re-charged. Such a method is possible in "mixed traction," for the battery has to be worked over only a short distance between each charge. Unless, however, the charging is frequent, the battery must be large, and the dead weight, which for other reasons should be reduced as far as possible, is increased. In the case of lines having no trolley-equipment, the cars would have to be run into the charging-station on completing each round trip, which involves more labour and a larger number of cars than would otherwise be necessary. It might possibly be worth while to erect a trolley-line for a certain length of track near the powerhouse, so that the battery of every car would be receiving a charge so long as its particular car was on the trolley section of the track, the battery being charged at practically constant potential. It is, however, probable that if a trolley-line were erected over part of the track, it would be found preferable to have a trolley system throughout, unless there were some prohibition against the use of this system.

The mode of carrying the battery is a matter of some importance. Several methods are in use, each having certain advantages, so that a suitable choice in any particular case cannot be made

without considering the conditions under which the line is to be operated. The simplest method is to place the cells permanently in position under the seats, their weight being supported by the floor of the car-body. To permit of inspection, the tops of the seats are screwed down with rubber joints so that they are gas-tight and yet may be easily removed. Some form of ventilation is generally provided to allow the gases to escape. When the arrangement is properly carried out it appears to be satisfactory, but otherwise it is liable to give annoyance to the passengers and to cause deterioration of the body of the car on account of the gases evolved by the cells. An objection to this method is that the car cannot be separated from the battery, and therefore if the latter becomes defective the car must be put out of use until the repairs to the battery are complete. This is equivalent to unemployed capital, and should therefore be avoided as far as possible. The method is also limited in its application, because the available space is only that under the seats. Consequently the capacity of the battery is restricted, and the method can be used only for light cars if each trip is lengthy, or in the case of heavy cars which have the opportunity of frequently charging. This method is therefore suitable for lines working on the "mixed system," because the batteries are charged at frequent intervals, namely, whenever the car is being run by the trolley. If the line is not a "mixed" one, it is necessary to arrange in some other way for frequent charging; in other words, a certain number of cars must be continually out of work, which, as already stated, is an undesirable condition. On the old system of charging at constant current, this proportion of unused cars would be large; but on the newer system of "rapid charging," or charging at constant potential, the proportion is much smaller. This system of charging is advantageous in that the capacity of a battery so charged is increased, but the efficiency, on account of the high mean charging-current is diminished, and the effect on the battery is probably harmful. The time required is generally 10 minutes to 15 minutes, and, in order that no inconvenience shall be caused to the passengers, the charging must be effected at one end of the line. If the power-station is not at such a point (and it is unlikely that it would be), it is necessary to lay feeders, and either to build a charging-station supplied from the main power-station, or to erect charging-pillars similar to those now used in the suburbs of Paris. Such pillars can, of course, be erected only on suburban roads where the

necessary space is available, space being required not merely for the pillars themselves but also for the number of cars which are being charged at any one time. Another method of carrying the cells, very similar to the system just mentioned, is that of placing the battery in a portable form under the seats of the car. In this case the battery is divided into several parts, which are contained in separate trays, and these are placed in position from the outside. The capacity of the battery is less than in the method already described, but this method has the advantage that the cells can be more easily inspected, and the car is not put out of use when the battery is being repaired, or when it is being charged. Charging may then be carried on as desired. There is also less deterioration of the car-body. On the other hand, if the batteries are not removed carefully they may be subjected to injurious shocks. From the point of view of handling of batteries, electric locomotives have much to recommend them. Small trucks, carrying the battery alone, would serve the same purpose, and are actually in use in Hanover and in Paris. But such an increased rolling-stock involves increased wear of the track, and would probably also require increased capital expenditure. In many respects it is preferable to have the battery supported directly upon the truck. The body of the car may then be the same as for electric traction with the trolley, and only of a strength sufficient for carrying the passengers. It is also less liable to suffer deterioration from acid fumes. If the battery is carried by the truck, between the wheels, it may all be contained in one case and handled as a whole. Since the weight to be manipulated at one operation is very much greater than when the battery is divided into several parts and placed under the seats, it follows that special plant is necessary for removing the batteries from the cars. In some respects the manipulation is not so convenient, because it is undesirable to have a large number of elevators, and therefore the cars must all come to the same spot to make a change of battery, the batteries being subsequently removed to suitable positions for charging. A car having a subdivided battery, on the other hand, can be run to any desired position between charging-tables, and the battery quickly removed by manual labour. With regard to capacity, the space available in the centre of the truck is limited in depth by the height of the floor of the car above the roadway, and is limited in breadth by the breadth of the car, or the gauge of the track. The space is further limited in length by the wheel-base, which in turn depends upon the

sharpest curve on the track. It is therefore sometimes found that the space available for the battery is not large enough. To meet this difficulty the battery may be divided into two parts, which are suspended from each end of the overhanging framework of the truck, as described later. Cars of this kind are now being used on some of the accumulator-lines in Paris. From the purely mechanical point of view, such a method appears objectionable on account of the heavier construction of the truck which it must entail.

There is probably no town in which so many different methods of tramway traction are to be found in operation as in Paris. Accumulator-traction has there existed for many years, either as traction by accumulators simply, or in the form of "mixed" traction, the trolley being used in the suburbs; in 1900 the total number of these accumulator-lines was nineteen. The following are particulars of accumulator-lines in Paris and elsewhere, most of which the Author has had an opportunity of inspecting.

Lines worked by the Compagnie Générale de Traction.—This Company works a number of accumulator-lines, among which may be mentioned those from St. Denis to the Madeleine, to the Opera and to Neuilly, the generating-station for which is at St. Denis. These lines have been running for the last 10 years or 11 years, and consequently important results might be expected from their working; but the crystallisation of results has been considerably delayed by changes which have been introduced from time to time. The cells first employed were made by the Société pour le Travail Electrique des Métaux, but during the last four years the Compagnie Générale de Traction has substituted Blot cells, and has manufactured plates for the line from Asnières. The route is not very favourable for accumulator-traction, as it includes gradients up to 1 in 20 and curves of somewhat short radius. On these lines there are twenty-six double-deck cars, built to carry fifty passengers, and weighing 16 tons, including the battery. The trucks were built to the design of Mr. Johannet, and have a wheel-base of 5 feet 11 inches; they are equipped with two Walker motors of 30 HP. each, and with air and electric brakes. The trucks are illustrated in plan and elevation in Figs. 4, Plate 6. The batteries consist of 180 cells per car, having a capacity of about 40 ampere-hours, and weigh 4 tons complete, including the cases in which they are carried. These batteries are subdivided into two batteries of ninety cells each, which are carried under the truck, one part at each end; the cells in each of these half-batteries

are contained in a wooden case, which is subdivided into three parts and is suspended from the truck. No particular care appears to be taken in insulating the cells, but the hooks which carry the case are insulated from the truck. The generating-station is at the extreme suburban end of the line. On completing each trip the car enters the station and the two half-batteries are removed simultaneously by two hydraulic elevators carrying trucks; the car is then moved along slightly, and fresh batteries are placed in position by two adjacent elevators. The operation is simple and is rapidly carried out. The batteries, being received on trucks, are readily moved along rails to any desired position for charging, during which operation they are placed in parallel. Two pressures are available for charging, viz., 220 volts and 250 volts, the latter being obtained by boosting. The Author was informed by Mr. Max Johannet, director of these tramways, that the plates used and made by the Compagnie Générale de Traction were ordinary Faure plates, of no particular type, and that their life was about 7,000 car-miles. The cost per car-mile was 2*d.* for maintenance and renewals and 0·46*d.* for handling, making a total of 2·46*d.* per car-mile. The accumulators are now being worked for about 1·8*d.* per car-mile, under a contract with the Blot Company.

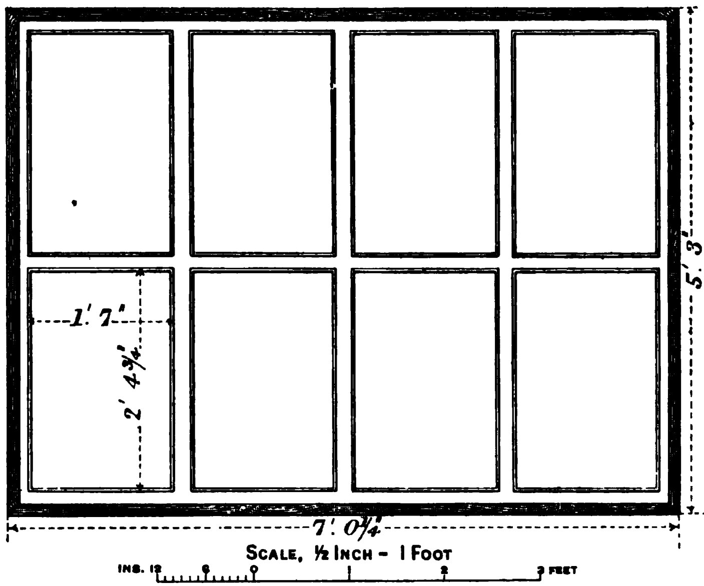
Lines Served by the Generating-Station at Puteaux.—The station at Puteaux, which commenced running in 1896, serves the following five lines:—(1) from the Madeleine to Levallois; (2) from the Madeleine to Neuilly and Avenue du Roule; (3) from the Madeleine to Courbevoie and Pont de Neuilly; (4) from the Madeleine to Courbevoie and Pont Binau; and (5) from Puteaux to St. Augustin. These lines, which are of the usual gauge, viz., 1·44 metre (4 feet 8½ inches), are operated by fifty-five double-deck accumulator-cars built to carry fifty-two passengers (five of these standing on the rear platform). The cars for the first four of these lines weigh 14 tons, including the battery, and are equipped with two 40-HP. Westinghouse series-motors. The battery consists of 200 Tudor cells, each weighing 38 lbs. complete with five plates per cell, or a total weight of 3·4 tons, the capacity being 40 ampere-hours. The cells are placed under the longitudinal seats of the cars. Two methods have been used for suitably preparing the receptacles under the seats, as indicated in Figs. 5 and 6, Plate 6. In the older method, shown in Fig. 6, Plate 6, the floor is covered with a sheet of glass about ½ inch in thickness, and the sides are covered with insulating paper, except near the bottom, where a strip of

rubber, about $\frac{3}{16}$ inch thick, is let in flush with the insulating paper. Along the top edge is fixed a rubber strip, so that a gas-tight joint results when the seat is screwed down. In the newer method, illustrated in Fig. 6, Plate 6, the rubber at the bottom extends from side to side beneath the glass plate, and the insulating paper is replaced by a coating of bituminous compound, which is applied to the wood-work. The ebonite boxes are provided with feet so that they are in contact with the glass over only a small surface, and provision is made for the escape of any acid which becomes spilt. No means of ventilation are provided. On the line from Puteaux to St. Augustin the Company has adopted trucks on which the battery is suspended in halves, one at either end, in a manner similar to that adopted by the Compagnie Générale de Traction. The positions occupied by the two cases, which are about 1 foot 7 inches in depth, are indicated in the plan of the truck shown in Fig. 7, Plate 6. The charging is done at constant pressure. There are at present five charging-stations, at suitable points, the most distant being about a mile from the generating-station at Puteaux. Each time a car returns to the suburban end of its journey the battery is charged for 15 minutes at a pressure of 540 volts. At that pressure the maximum current is 120 amperes to 125 amperes, and the amount of gas evolved is small; there is therefore no risk of explosion. A similar system is used on the line from the Louvre to the Cours de Vincennes, which is also equipped with Tudor cells. Eighteen men are required for the handling and maintenance of the accumulators at the Puteaux station. This labour does not include the manufacture of any plates.

Lines Served by the Generating-Station at Aubervilliers.—There are two lines served by this station, both running from the Place de la République, one to Aubervilliers, and the other to Pantin. These lines, which started in 1897, are worked on the mixed system, accumulators being used within the walls of Paris and the trolley system in the suburbs. There are twenty-four double-deck cars, built to carry twenty-two passengers inside, twenty-eight outside, and five on the rear platform. These cars, including the battery, weigh nearly 15 tons; they are fitted with two 25-HP. Thomson-Houston series-motors, magnetic and air brakes, and maximum traction bogie-trucks. Each battery consists of 208 Tudor cells, weighing 35 lbs. complete, with three plates per cell, and is contained in a case which is carried under the centre of the truck. The total weight of the battery, including the case, is about 3·87 tons, and the capacity is 45 ampere-hours. These cells have been

used only since October, 1899. A difficulty experienced when the cells are all contained in one case is that the woodwork is liable to be set on fire by leakage. For this reason the Company has found it necessary to use the arrangement shown diagrammatically in *Fig. 8.* The battery is divided into eight sections, each of which is contained in a case, these cases being slightly separated from each other and contained in one large outer case. The inner cases are each supported on eight insulators, as shown in Fig. 9, Plate 6.

Fig. 8.



In order to avoid the formation of an arc at any time, the height of these insulators should not be less than about 1½ inch. Both the inner and the outer cases are perforated through the bottom, so that any acid that is spilt may escape. The Author was informed that the insulation of a battery so mounted is often as high as one megohm; and in order that it should be safe from fire, the insulation resistance should be at least 20,000 ohms. The batteries are charged entirely on the trolley-line, the pressure being 510 volts at the station and 480 volts at the most distant point. There is, therefore, a somewhat convenient and automatic raising of the pressure as the car approaches the station and the battery

becomes charged. On the Aubervilliers line the length of route worked by the trolley is 1·2 mile, and that worked by accumulators is 3 miles, while the corresponding distances on the Pantin line are 1 mile and 2·9 miles respectively. Consequently the distance over which charging takes place is only about one-half to one-third that over which there is a discharge. In all there are thirty-one batteries for operating the twenty-four cars, giving a reserve of seven batteries. The electro-motive force of every cell in each battery is tested every night, and the specific gravity of the acid in a certain proportion of the cells is determined. If any small repairs are necessary they are carried out at once, but if anything is seriously wrong the battery is put out of service for repairs to be effected at leisure. Fourteen men, of whom four are on night-duty, are required for the handling and maintenance of the batteries.

The city of Paris is not altogether suited for accumulator-traction, owing to the somewhat frequent gradients and sharp curves. The cars, also, are unnecessarily heavy, owing to the compulsory use of air-brakes. An average figure for the complete maintenance of accumulators (including renewals) on lines of the class just described is 1·62*d.* per car-mile, assuming that the tramway company has to purchase plates instead of manufacturing them. This figure applies approximately to a car-mile run by accumulators, whether the system of traction is "mixed" or by accumulators only, but the mixed system is slightly the more expensive of the two. The Tudor positive plates last for 25,000 car-miles to 28,000 car-miles, while the negative plates last for 15,500 car-miles to 18,700 car-miles. These figures are noteworthy on account of the longer life of the positive plates as compared with the negative.

Hanover.—The system of mixed traction at Hanover is on so extensive a scale that any results there obtained are of unusual interest. In 1898, at the Geneva meeting of the Union Permanente de Tramways, Mr. Krüger, the Director of these tramways, presented an important Report, which has not received the attention in this country which it deserves, and from which the following information is derived. In 1898 the system consisted of fourteen lines, extending over 79·3 miles, of which 39·1 miles were worked with the trolley and 40·2 miles by accumulators. Three of these lines were worked with the trolley only, and one line appears to have been worked entirely by accumulators, the remainder being mixed lines. The number of

cars was one hundred and sixty-nine. The batteries consist of 202 Tudor cells, with one positive and two negative plates, made by the "Accumulatoren Fabrik A.G.," and are placed under the seats of the car. Their capacity is 25 ampere-hours when discharging at 25 amperes, and the plates are so mounted that there is a clear depth of 1·57 inch below them in which any deposit may collect. Ventilation is effected by means of a current of air which enters at the front and leaves at the rear of the car. The complete battery weighs 2 tons to 2½ tons, according to the state of the plates. The batteries are subjected to the most systematic treatment. Every evening when the car stops running, each battery is charged until gassing takes place at both the positive and negative plates. An inspection is made, so as to remove any defects, and water is added to the cells where necessary (generally to one-third of the number) to compensate for evaporation. The electromotive force of every cell is measured once a week, and any internal short-circuits, which are generally the cause of low voltage, are removed. If a cell is still found to be defective the following week, it is cut out of circuit. In addition to these tests, the batteries are examined every week with regard to the depth of the deposited mud, the density of the acid, the oxidation of contacts, the state of the glass tubes between the plates, the ebonite boxes, the wood covers, and the efficiency of the ventilation. In the case of the Glocksee Station, where there are seventy cars, all this night-work is carried out by three men. After running 5,000 miles to 7,500 miles, the distance depending upon the electrical conditions under which the battery has to be worked on the line on which it is placed, the acid is removed from the battery and the mud is pumped out. Before the acid is replaced it is made up to the usual strength (1·210) if the density is incorrect. Finally, when the battery is re-charged, a capacity-test is made, so that the battery may be placed on the line most suited to its capacity, where it remains until a repetition of the operation takes place. As soon as the capacity falls to 12 ampere-hours at a discharge-rate of 25 amperes, the battery is placed only on the easiest lines, where a capacity of 4 ampere-hours to 8 ampere-hours is sufficient, and this is permitted only until another removal of the mud becomes necessary. The battery is then dismantled, and new plates are put in. Positive plates which are still capable of service are further used as renewals in old batteries, but the worn-out plates are sold as lead. Negative plates, on the other hand, are re-pasted and are then as good as new. This re-pasting may

be continued until the plate fails mechanically, the limiting number of re-pastings being placed by Mr. Krüger at six, corresponding to 150,000 car-miles, run by the accumulators, excluding the trolley. Mr. Krüger lays great stress upon the importance of constant inspection and rigorous control of the accumulators, and he remarks that their duration depends entirely upon the method of treatment and upon the proportion between their capacity and the work to which they are regularly subjected. In addition, the density of the charging-current is a matter of importance. For example, if a positive plate having a surface of 1,320 square inches, like those at Hanover, is charged at 150 amperes (*i.e.*, in 10 minutes), after a full discharge, the maximum life will be 12,500 car-miles. Under the same conditions the negative plates will not run more than 11,200 car-miles, because the capacity is insufficient. If it is desired to double this life, the dimensions of the cells must be increased so that only half the capacity is employed, and, further, the time of charge should be at least doubled. It is then always possible to obtain a life of 22,000 car-miles to 25,000 car-miles. These figures are confirmed by the results obtained for thirty-seven batteries, which gave a mean of 23,435 car-miles for positive and negative plates. Between 1 August, 1896, and 1 August, 1898, 2,670,233 car-miles were run by accumulators alone, and a total of 5,077,005 car-miles by accumulators and trolley. The mean cost of maintenance of the accumulators during this time was 0·394*d.* per car-mile run by accumulators, or 0·209*d.* per car-mile for the total mileage.

At the International Tramways Congress, held in Paris in 1900, Mr. Krüger stated that the cost of maintaining the accumulators, the plates being manufactured by the Tramway Company, was equivalent to an increase in the price of raw lead to the extent of 0·106*d.* per pound, or that the cost of maintenance and renewals (including accessories) had then fallen to 0·235*d.* to 0·3*d.* per car-mile run by accumulators, or 0·094*d.* to 0·113*d.* per "mixed" car-mile. In these figures, which are so extremely low that some engineers may feel somewhat sceptical about accepting them, the term "mixed car-mile," in addition to the mileage run by accumulators, includes only that part of the service during which the accumulators are being charged from the trolley-line. Since many of the trolley-lines in Hanover are of considerable length, it is unnecessary to keep the battery connected to the trolley throughout. The additional expenditure of energy required for carrying

the battery is 80 watt-hours per ton-mile. Another point of interest, although of less importance than the question of maintenance, is the introduction, at Hanover, with satisfactory results, of tenders for carrying the accumulators. These are detached at the end of any accumulator-section, and are charged from the trolley-line, thus enabling long trolley-lines with short accumulator-sections to be worked efficiently.

Ostend.—The accumulator-line at Ostend is of interest as an example of the kind of line which may be worked to advantage with accumulators, but which would probably be less successful if worked by the trolley, owing to the increased capital expenditure. The line, which is of metre gauge, is a closed track running round part of the town and along the sea-front, a distance of about 2½ miles, and is in operation only during 3 months of the season. For the greater part of its length the line is flat, but there is one gradient of 1 in 18 for a distance of 230 feet. Outside the town Vignoles rails are used, but most of the track is laid with a light guard-rail, so that it is equivalent to a girder-rail construction. The line is operated with three single-deck cars, built to carry fifty passengers, and weighing 13 tons, including the battery. The trucks are simple in their construction and were designed by Mr. de Cuyper, the engineer to the Company. They are equipped with two 25-HP. series-wound Westinghouse motors. The batteries, of which there are six, consist of 108 cells per car, with a capacity of 165 ampere-hours, and weigh 2 tons complete with the cases in which they are carried. Laurent-Cély, Marschner and Monobloc cells have been employed, the latter predominating at the present time. The batteries are subdivided into twelve sections, each section being contained in a separate case. These cases are placed under the two longitudinal seats of the car, six on each side. The operation of changing a battery is simple and is effected rapidly by two men, the car being run between two charging-tables which extend the length of the car-shed. During the part of the year when the line is not running, the cells are dismantled, the Monobloc plates being stood in acidulated water having a density of 3° Beaumé; the plates of the other batteries are allowed to dry. The generating-plant consists of a 60-HP. steam-engine, of the semi-portable type, driving a Westinghouse dynamo giving 135 amperes at 280 volts. This pressure is cut down when necessary by inserting resistance, the method of charging being the usual one of constant current. The Author was informed by Mr. de Cuyper that the cost of complete maintenance

of the batteries, including renewals, was about 1·07*d.* per car-mile. Plates are made at the station as required. Mr. de Cuyper has kindly supplied the Author with detailed figures of the running costs for the two years 1899 and 1900. These, together with some earlier figures, are given in the Appendix, Table I. In this Table the handling of the batteries and their maintenance are not separated, for the reason that the men who handle the batteries for charging also effect any maintenance that is required. The total cost is seen to be very low, which is due to the fact that the cost of renewals, amounting to 0·77*d.* per car-mile, is omitted. It should be noted that this latter sum also includes the cost of dismantling the batteries at the end of the season, and their re-erection at the beginning of the next season. It will be observed that the cost per car-mile in 1900 was higher than that for previous years, owing to the rise in the price of fuel; but still the cost is remarkably low, being 2·987*d.* per car-mile, or 3·757*d.* per car-mile including renewals, which is less than the usual cost for electric traction by means of the trolley. This is no doubt due to the peculiar circumstances of the case, items being absent which would necessarily appear in the costs of a larger concern. For example, salaries and general expenses are omitted, as also is the cost of maintenance of generating-plant and of buildings. Moreover, labour is exceptionally cheap in the neighbourhood of Ostend. On the other hand, there may be some items which would cost less in the case of a larger network. The saving of capital in generating-plant is well exemplified at Ostend, where considerably more plant, entailing also increased attendance, would be necessary if a trolley-line were in use, instead of batteries. The energy required at the switchboard is 80 watt-hours per ton-mile.

Ghent.—The use of the trolley being prohibited in Ghent, it was decided to employ accumulators, Monobloc cells being selected as the result of the experience at Ostend. In general, the town is flat, but there is one long gradient of 1 in 25, and sharp curves are rather frequent, so that the town is not altogether favourable to this form of traction. The lines, which are of metre-gauge, were opened in January, 1899. The number of cars in operation varies between thirty-two and thirty-eight, the total number being about forty. They are built to carry twenty passengers inside and twenty on the platforms. Their weight, which is considerable, the cars having been originally built for use on light railways, is 13 tons, including the battery. The trucks are of simple construc-

tion, and are equipped with two 25-HP. series-wound Westinghouse motors. Trailers are used on Sundays and holidays. The line is worked by seventy batteries, each of which consists of 108 Monobloc cells. As at Ostend these are subdivided, but are contained in six instead of twelve cases, which are placed under the seats, three cases on each side. The weight of a cell is about 40 lbs., and that of the battery, complete with the cases, is 2 tons. The arrangements for charging are simple and effective. The car-shed is provided with six tracks, between which are charging-tables. Upon entering the yard the driver rings his bell and the switchboard attendant thereupon switches on a lamp over the track leading to the most convenient vacant place for the battery. Upon seeing the signal, the driver runs the car into the shed on the selected track. The battery is removed and a charged battery is substituted for it, this work being done by hand. At the end of the charging-shed, and extending nearly its entire width, is the switchboard, consisting of twenty-four double panels, thus giving forty-eight battery circuits. Each circuit is provided with an ammeter, a rheostat, and a throw-over switch. Two pressures are available—one of 260 volts, which is obtained direct from the dynamos, and the other of 275 volts, obtained by boosting. The battery is first put on the 260-volt circuit, and the resistance is varied so as to maintain a current of 50 amperes. When the resistance has all been cut out and the current can no longer be maintained, the battery is placed on the 275-volt circuit by means of a throw-over switch, and the current is further regulated in the same way. The battery is considered to be charged when, after all the resistance has been cut out, the current falls to 35 amperes on this higher pressure. The Author was informed by Mr. Bayet, director of "l'Electrique," the company at Brussels who manufacture the Monobloc cell and are responsible for the treatment and maintenance of the accumulators at Ghent, that the batteries are washed after about 4,500 miles, and that they run 19,000 miles to 25,000 miles. The positive plates, at the present time (March, 1901), have a life of 20,000 car-miles, and there is no difficulty in running 23,000 car-miles to 25,000 car-miles, but this is probably the limit. The negative plates have a life of 31,000 miles to 38,000 miles. The energy required at the switchboard is 128 watt-hours per ton-mile. The tramway pays the Electric Company 1·07*d.* per car-mile for everything in connection with the accumulator service. This sum, therefore, includes the handling of the batteries in charging, maintenance, and washing, as well as renewals of plates,

boxes, acid, etc. The Author is informed by the Electric Company that this contract has been worked at a loss owing to a rise in the prices of raw material, but that during the present year (1901) the cost will be about 1*d.* per car-mile, and that the Company would be willing to contract again on the same terms.

Dunkirk.—This town, like Ghent, also began running accumulator cars in January, 1899, equipped with Monobloc cells. The gauge is broader than at Ghent, being 1·435 metre (4 feet 8½ inches). There are fourteen double-deck cars (four of these being in reserve), built to carry fifty-two passengers, and weighing 11 tons, including the battery. Trailers weighing 2½ tons are frequently used, and, like the motor-cars, are capable of carrying fifty-two passengers. The batteries, weighing only 1 ton, consist of seventy-two cells, and are suspended in a case under the centre of the truck. The method of charging is similar to that adopted at Ghent. The batteries are washed after they have run 5,600 miles, which is a longer distance than that allowed at Ghent. This is accounted for by the fact that the suspension of the batteries at Dunkirk is more satisfactory and diminishes the effects of jolting. The plates last practically the same number of car-miles as at Ghent, or for a slightly greater number. The Company l'Electrique supplies the motive power under a contract, receiving 1·84*d.* per car-mile for works' costs (coal, oil and stores, and labour), maintenance and repairs of generating plant and rolling-stock, and maintenance of batteries (excluding renewals). For renewals the Company receives in addition the sum of 0·485*d.* per car-mile. The Author is informed by the Company that this contract has been worked at a loss, but that the loss is not attributable to the accumulators in themselves. The contract was signed in 1897, and since then the price of coal has risen from 17 francs to 27 francs (13*s.* 7½*d.* to £1 1*s.* 7½*d.*) per ton. There has also been a great increase in the price of lead, and a rise in other things, even in labour, with the result that the cost has been 2·18*d.* per car-mile. The energy required at the switchboard is 96 watt-hours per ton-mile, which is less than at Ghent. This is explained partly by the better design of the cars and partly by the greater width of groove in the rail.

A comparison of the methods and results at Ghent and at Dunkirk shows many points of interest. At Ghent the batteries weigh 2 tons, and the total weight of the car is 13 tons, whereas at Dunkirk the batteries weigh only 1 ton, the total weight being about the same. Considering that trailers are frequently used at Dunkirk, it

follows that the total weight propelled by the 1-ton battery is often more than that propelled by the battery of 2 tons weight, the distance with one battery-charge, however, being less. Moreover, the trains at Dunkirk consist of two double-deck cars, each for fifty passengers, whereas at Ghent they consist of two single-deck cars, each for forty passengers. Notwithstanding the heavier work for the lighter battery at Dunkirk, the results are better than at Ghent. The Electric Company attribute this result to the better design of the cars at Dunkirk. Each battery, being manipulated as a whole, is subjected to much less shock, a fact which is proved by the extremely rare occurrence of broken ebonite boxes. On that account the batteries at Dunkirk are joined simply in series, whereas at Ghent means are provided for running on only one-half of a battery in case a breakage occurs. Great stress is laid upon the importance of utilizing only half the available capacity of the batteries. For example, the batteries at Ghent are capable of running 43·7 miles on one charge, but they are permitted to run only 19 to 22 miles. At Dunkirk the limit is 12·5 to 15·6 miles. The result is a low maintenance-cost, and a reserve of capacity in case it is required, with consequent immunity from breakdown.

Unfortunately it is a difficult matter to obtain trustworthy information as to cost of maintenance of the batteries used by accumulator-lines, owing to the fact that the maintenance is always carried out under a guarantee by the firm supplying the accumulators, and secrecy as to details is generally desired by such a firm if it is working at a profit, and equally, although for different reasons, if it is working at a loss. It appears, however, in the case of the lines already described, that the cost of maintenance varies approximately between 1·075*d.* for light cars and 2·46*d.* per car-mile for very heavy cars. The Author is informed by Mr. Grindle, engineer of the Chloride Accumulator Company, that the cost of renewing batteries and replacing the plates on the accumulator-lines at Birmingham amounted to 0·45*d.* per car-mile, but this does not include the cost of handling the batteries for charging. The life of batteries was found to be 29,000 car-miles. The various costs for maintenance given in connection with the lines just described are summarised in the Appendix, Table II.

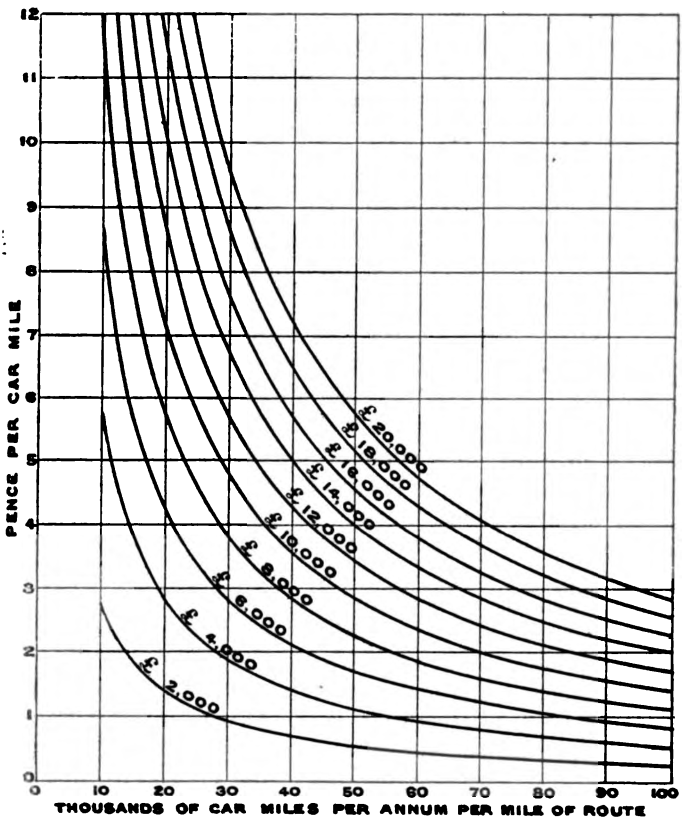
Comparative Cost of the Various Systems.

In order to make a comparison of the cost of the various systems of electric tramway-traction, it is necessary to take into account both capital expenditure and running expenses. Since these are not quantities of the same kind, it is best in some way to reduce one to the other; for example, to consider running expenses as equivalent to so much capital on which interest has to be paid at a fixed rate, say 6 per cent., the running expenses being equal to the interest. If this derived capital be added to the actual capital expenditure the result may be compared with that obtained for some other system with different running-costs and capital. For this purpose it is convenient to make calculations for different numbers of car-miles per annum per mile of route, it being first decided whether single or double track is required. By representing the results graphically it may be readily seen to what extent one system or another is to be preferred, according to the traffic to be handled. The cost of maintenance per car-mile is frequently more or less a constant quantity; but the relative importance of capital expended per mile of route depends upon the car-mileage per mile of route. This is shown clearly by the curves in *Fig. 10*, in which each curve shows the variation of the charge per car-mile with traffic for a definite capital expenditure per mile of route, interest being taken at 6 per cent. If these capital charges per car-mile be added to the running costs, different systems may be readily compared; but this method does not lend itself to graphical treatment quite so readily as that in which running-costs are represented by equivalent capital, and the latter method will therefore be used in the comparisons which follow. The rate of interest is taken at 6 per cent., because that amount covers interest and sinking-fund in the case of local Authorities, and because it represents such a dividend as a commercial company would seek to pay.

The Trolley System.—For the purposes of comparison it is only necessary to consider the overhead equipment, the bonding and the feeders. There is, of course, no doubt that, in general, the trolley system is the cheapest form of electric traction. In dealing with a small amount of traffic, however, it may happen that accumulators provide a cheaper solution. There are also many instances of the trolley system being inadmissible, as, for example, in the centres of large towns. In these cases, however, the traffic is heavy, and it

becomes a question whether the heavier maintenance-charges of accumulators are a more serious matter than heavier capital expenditure, such as is involved in the use of a conduit system. Consequently, in making a comparison of these various systems, it is necessary to consider two cases:—(1) that in which the traffic is

Fig. 10.



light and the comparison is between accumulators and the trolley-system; (2) that in which the traffic is heavy and the comparison is between accumulators, the conduit system, and the surface-contact system, as well as the trolley system.

For the first case let it be assumed that the traffic is 50,000 car-miles, and for the second case 250,000 car-miles, per annum per

mile of route. It is, of course, impossible to take figures of cost which shall be strictly applicable to every case, as the cost must necessarily vary considerably according to the conditions; but for the purposes of this comparison the cost of the trolley-system may be taken as £3,500 per mile of single track, or £4,000 per mile of double track, of which about £1,500 would be spent on feeders. These figures apply to the first case. In the case of the heavier traffic, double track would be laid as a matter of course, and the cost per mile of route would be, say, £5,500, in which about £3,000 is included for feeders. As to the variation of these figures with car-mileage, the cost of overhead line and bonding remains practically a constant quantity. The cost of feeders increases with the traffic, but not in direct proportion; it may be convenient to assume that half the cost of the feeders varies in direct proportion to the traffic, throughout the range of any comparison. The cost of maintenance of the overhead line may be taken at 0·07*d.* per car-mile. Allowing 4 per cent. for maintenance and depreciation of feeders, the running costs are shown in the following Table :—

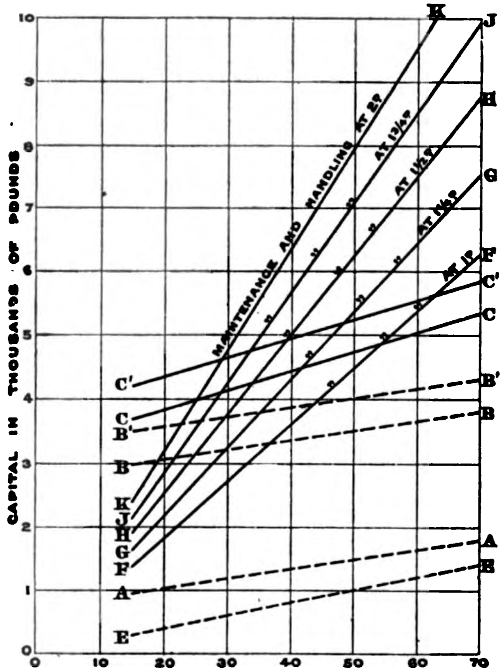
Car-mileage.	Overhead Line.		Capital in Feeders.	Feeders per Annum.	Total per Annum.	Equivalent Capital at 6 per cent.
	Per car-mile.	Per annum.				
Miles.	*d.*	£	£	£	£	£
50,000	0·07	14·6	1,500	60	74·6	1,243
30,000	0·07	8·75	1,200	48	56·75	946
250,000	0·07	73·0	3,000	120	193·0	3,217
200,000	0·07	58·4	2,700	108	166·4	2,773

In *Fig. 11*, referring to the case of 50,000 car-miles per annum per mile of route, the line A A relates to the capital expenditure on feeders, and is therefore inclined to the axes. The line B B is obtained by drawing a line parallel to A A, but with ordinates increased by £2,000 so as to represent the total capital expenditure in the case of single track. For double track the ordinates have to be increased by £2,500 instead of £2,000, giving the line B′ B′. Finally, the capital has to be increased by the capital equivalent to the running costs—*i.e.*, by £946 at 30,000 car-miles and by £1,243 at 50,000 car-miles, giving the lines C C and C′ C′, which give a measure of the cost of the trolley system on single and double track respectively. The case of 250,000 car-miles per annum per mile of route is given in *Fig. 12*. Here the cost of

feeders is £3,000 for this mileage, instead of £1,500, and is again represented by the line A A. The line B B is parallel to A A, but with ordinates increased by £2,500 so as to represent the total capital expenditure. Finally, the capital is increased by the capital equivalent to the running costs, viz., by £2,773 at 200,000 car-miles, and by £3,217 at 250,000 car-miles, giving the line C C.

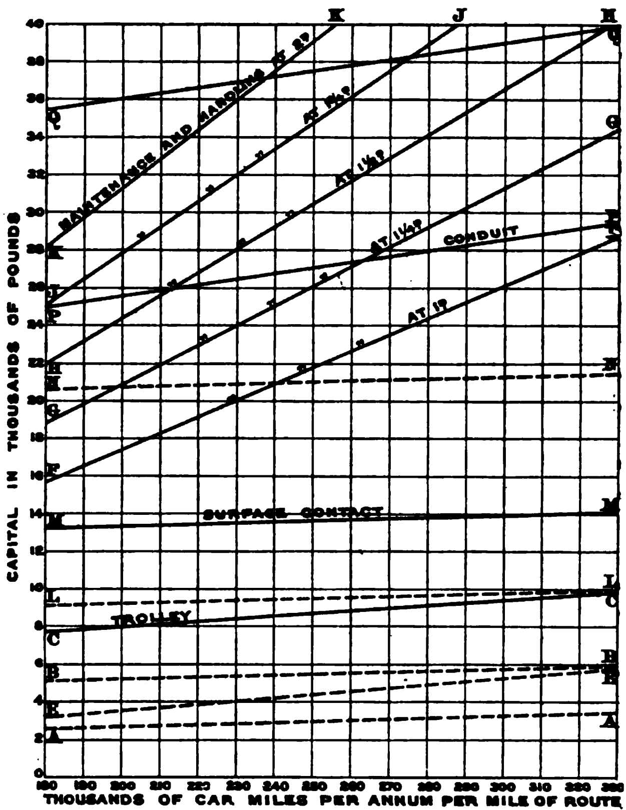
The Accumulator System.—Assuming that a car runs 85 miles a day, and making a certain allowance for spare plant, it will be sufficient to have $2\frac{1}{2}$ cars per mile of route for 50,000 car-miles. The comparison which is here given refers to the system in which the cars are provided with duplicate batteries, and feeders are therefore absent. If rapid charging were adopted, the number of batteries would be halved, but feeders would most probably have to be laid down, and the capital expenditure would be correspondingly increased. Putting the cost per battery at £250, the capital per car is then £500. Against this may be set a certain saving in the generating-plant. In generating-stations which feed a line directly, it may be said that the mean load often requires only half the plant which is required for the maximum load. By suitable management the load may be made practically uniform in the case of accumulator-traction, and therefore a certain amount of plant may be omitted. On the other hand, the efficiency of batteries is not so high as the efficiency of direct distribution to the line, and consequently the energy required is increased to the extent of one-quarter to one-third. On that account it is often wrongly assumed that the cost of accumulator-

Fig. 11.



traction is correspondingly increased. This, however, is a mistake, for in the one case the steam-plant is working on a very variable load, and for the greater part of the time is much under-loaded; whereas, in the other case, the plant may be worked on a steady and efficient load. Consequently, although a larger amount of electrical energy has to be generated, it is produced under more

Fig. 12.



favourable conditions and therefore more cheaply. In practice these factors are likely to counterbalance one another, so that the coal-bill remains much the same as it would be with direct distribution. These remarks do not apply to stations in which a buffer-battery is used for the equalization of the load on the generators. Owing to the increase in the energy required, the saving in plant is not so great as it would be otherwise, but

assuming a saving of one-third at a cost of £30 per kilowatt, the saving in capital cost of plant might be put down at, say, £100 per car. The net capital cost per car, for the purpose of comparison, would then be £400, or a total of £1,000 per mile of route in the particular case under consideration. In *Fig. 11* this capital expenditure is given by the line E E, on the assumption, which is reasonable within limits, that the capital is proportional to the car-mileage. The equivalent capital for various rates of maintenance, for 50,000 car-miles per annum, is given in the following Table:—

Rate of Maintenance and Handling.	Total per Annum.	Equivalent Capital at 6 per Cent.	Total Capital.
Pence per Car-mile.	£	£	£
1·0	208·3	3,472	4,472
1·25	260·4	4,340	5,340
1·5	312·5	5,208	6,208
1·75	364·5	6,075	7,075
2·0	416·6	6,943	7,943

The "total capital," by which is meant the sum of the actual capital and the equivalent capital, is found by adding £1,000 to the equivalent capital, that being the amount expended per mile of route. The total capital in these cases is represented in *Fig. 11* by the lines F F, G G, H H, J J, and K K, which pass through the origin and through points having the values given in the foregoing Table as ordinates corresponding to 50,000 car-miles. Where these lines cross the line C C, the cost of the trolley-system is equal to that of the accumulator-system at the given rate of maintenance for the traffic represented by the abscissa at the point of intersection. Thus it appears, on the assumption stated, that accumulator-traction, with maintenance and handling at 1*d.* per car-mile, is cheaper than the trolley-system with single track, if the traffic is less than 54,000 car-miles. But if the cost of maintenance and handling is 1½*d.* per car-mile, this limit drops to 34,000 car-miles for single track, and to about 40,000 car-miles for double track, and if the cost is as high as 2*d.* per car-mile, the limits drop still further, namely, to 25,000 car-miles and 29,000 car-miles respectively.

For the second case under consideration, it will be assumed that eleven cars are required per mile of route for 250,000 car-miles, the number being proportional to the car-mileage. The capital

involved in batteries is then £4,400 per mile. The equivalent capital for various rates of maintenance, for 250,000 car-miles per annum, is given in the following Table:—

Rate of Maintenance and Handling.	Total per Annum.	Equivalent Capital at 6 per Cent.	Total Capital.
Pence per Car-mile.	£	£	£
1·0	1,042	17,367	21,767
1·25	1,302	21,700	26,100
1·5	1,563	26,050	30,450
1·75	1,823	30,383	34,783
2·0	2,084	34,733	39,133

In this case the total capital is obtained by adding £4,400 to the equivalent capital. All these amounts are proportional to the car-mileage, and are therefore represented by lines passing through the origin and through points having, for the ordinate corresponding to 250,000 car-miles, the values given in the Table. Thus the capital outlay is given by the line E E (*Fig. 12*); and the total capital for the foregoing rates of maintenance and handling by the lines F F, G G, H H, J J, and K K. From these it is seen that accumulator-traction, even at the low cost of 1*d.* per car-mile for maintenance and handling, compares very unfavourably with the trolley-system for heavy traffic.

The Surface-Contact System.—It may be assumed that the cost of a surface-contact system, excluding track, amounts to £6,500 per mile of double track, the feeders costing, as before, £3,000 for 250,000 car-miles. The cost of maintenance is to a large extent independent of the car-mileage, and for the purpose of this comparison it will be taken as a constant quantity. Assuming £250 per annum per mile of double track as the cost of maintenance, the equivalent capital is £4,167. The case is shown graphically in *Fig. 12*. The cost of feeders is again represented by the line A A. The total capital expenditure is obtained by increasing the ordinates of this line by £6,500 giving the line L L, and the total capital by adding £4,167 representing the equivalent capital, thus giving the line M M as the final result. This line shows that a surface-contact system, on these assumptions, is considerably more costly than a trolley-system, but is nevertheless cheaper than accumulator-traction. Cost, however, is not the only consideration in this case.

The Conduit System.—Taking Mr. Connett's figures for a conduit system and remembering that the cost of overhead line and bonding must be included for the purposes of a comparison, it may be

assumed that the cost of double track will amount to £18,000 per mile. Feeders will cost £3,000 per mile as before, and will again be represented by the line A A in *Fig. 12.* The total capital cost is therefore found by increasing the ordinate of A A by £18,000, giving the line N N. The maintenance is to a large extent independent of the traffic, but figures are not available to show to what extent that is the case. A constant maintenance-cost will therefore be assumed, viz., 0·35*d.* per car-mile. The capital equivalent to this will be—

Car-miles.	Maintenance per Annum.	Equivalent Capital.
	£	£
200,000	292	4,867
300,000	437	7,283

The line P P (*Fig. 12*), representing total capital, is therefore found by increasing the ordinates of N N by £4,867 at 200,000 car-miles and by £7,283 at 300,000 car-miles. This line shows that accumulator-traction at 1*d.* per car-mile for handling and maintenance is cheaper than a conduit system. If the charge is 1¼*d.* per car-mile, it is cheaper only up to 263,000 car-miles per annum, and if the charge is 1½*d.* per car-mile this limit is reduced to 212,000 car-miles. Whereas, however, a surface-contact system may be kept in perfect order permanently by suitable maintenance, a time may come in the history of a conduit system when the conduit has to be renewed completely. In the case of a local Authority this might not be serious, but in the case of a Company it becomes necessary to provide a sinking-fund for the purpose of meeting this renewal. For example, if it were necessary to renew the conduit in 20 years, then 3½ per cent. on £18,000, or £630, would have to be set aside annually. This is equivalent to an increase in capital of £10,500, and if the ordinates of the line P P (*Fig. 12*) are increased to that extent, giving the line Q Q, it is seen that accumulator-traction with a charge of as much as 1½*d.* per car-mile for maintenance and handling is cheaper than the conduit system under these conditions. If the charge is 1¾*d.* per car-mile, accumulator-traction is cheaper up to 275,000 car-miles; while if the charge is as high as 2*d.* per car-mile this limit falls to 237,000 car-miles. If the period of renewal is shorter the comparison is still more in favour of the accumulators. Unfortunately this question of maintenance is one on which information is still wanting, so that no very definite statements can be made. It will,

however, be generally admitted that high maintenance-charges are to be preferred to high capital cost, supposing the cases to be equivalent, because the risk is less. The results deduced in the foregoing comparisons are, of course, only true for the assumptions that are made. They will vary with the rate of interest selected and with the cost of any particular system. Any actual case must be examined on its merits. The results here given are only put forward to illustrate the problem, and to show that under certain conditions accumulator-traction may be found preferable to other systems.

Electric Traction on Ordinary Roads.

In the case of vehicles on ordinary roads, accumulators give the only general and practicable solution of electric locomotion. In many respects this method is an ideal one, providing easy running and motive-power ready at a moment's notice. The difficulties, however, are even greater than in accumulator tramway-traction. Regularity of treatment is probably essential to success; but in the case of accumulator-cabs no very exact supervision can be exercised over the cabman, and in the case of private carriages the batteries are liable to pass still more into non-technical hands. Moreover, the conditions of roads vary from day to day, and therefore what is permissible one day may be dangerous the next. Unfortunately the conditions to be fulfilled are conflicting. The general public require a long run with one charge, yet it is desirable that the weight should be small. But if a light battery is used it is likely to be wanting in mechanical strength; the capacity also is likely to be small, and a long distance cannot be covered without the risk of over-discharge and consequent loss in capacity. The difference in output between safe discharge and over-discharge, in some batteries at least, is very small indeed; and as a simple voltmeter-reading is of little value for indicating the state of the cell, unless taken when the battery is discharging at some definite rate, it is easy to cause rapid deterioration without realising the danger before the mischief is done. What is really required for such a purpose is a battery which can be completely discharged without damage to its capacity. Owing to the lightness, and consequently the small capacity, of the batteries used on automobiles, the risk of over-discharge is considerable, and it becomes most necessary to have some means of indicating to the driver when he should return to the charging-station. Probably the simplest method of doing so would be to have every

carriage equipped with some simple form of watt-hour meter, or ampere-hour meter, calibrated to indicate when the carriage should be returned to the station, and adjusted to allow a large factor of safety. Unfortunately, vibration renders the employment of instruments in this way a difficult matter. The problem is most complicated in the case of private carriages, because there is no control except by the owner, who may be quite ignorant of technical matters. It is unlikely that such carriages will come into general use until convenient charging-stations are equipped, and until manufacturers can devise a system on which they can guarantee the maintenance of the battery, unless indeed some new form of accumulator is devised which does not suffer by complete discharge. The only serious attempts, so far, have been in the direction of electric cabs. Companies are now working in New York and elsewhere, but unfortunately the attempts in this country and in Paris have failed, and the industry has no doubt suffered on that account. Much useful information would doubtless be gained if the causes which led up to this failure were made known. Whatever may have been the causes of failure, it may be said that if success in tramway-traction by accumulators depends to a great extent upon attention to details, success in electric automobiles must depend still more upon this principle. In many ways the problem of electric omnibuses is simpler than that of electric cabs. The number of car-miles per trip can be definitely fixed, and therefore the battery can be designed accordingly, and can be subjected to treatment of a perfectly regular kind. Consequently the maintenance should be less than in the case of cabs. When compared with tramways, electric omnibuses have the great advantage that capital is saved by avoiding track costing £5,000 or more per mile when single, and the expenses of promotion are also much smaller, but there is the disadvantage that the capacity per car for the same working-costs is only about one-half.

The main question, however, is whether omnibuses can be run more cheaply electrically than by means of horses. The first cost of an electric omnibus, provided with a duplicate battery, is not likely to be less than that of an ordinary omnibus with the necessary number of horses; therefore, if any saving is to be made it must be effected in the costs of running. An examination of the results obtained by the London General Omnibus Company shows that the receipts for the year ending 31st December, 1900, were 9·44*d.* per car-mile, and the expenses 8·9*d.* per car-mile, giving the small margin of 0·54*d.* per car-mile, which was, however, sufficient to pay a dividend of 10 per cent. Owing to the

heavy cost of maintenance of the horses and the comparatively low receipts, the expenses amount to over 90 per cent. of the receipts, a very different figure from that which is obtained on tramways. It follows, therefore, that a small saving in the cost of running, say ½*d.* per car-mile, would make a very great difference in the financial position of a Company of this kind. The cost of horsing omnibuses, including the complete maintenance of the horses, appears to vary between about 4*d.* per car-mile and 6*d.* per car-mile. The cost to the London General Omnibus Company of maintaining horses and harness during 1900 was 4·50*d.* per car-mile, to which, for the purposes of the present comparison, must be added 0·82*d.* per car-mile on account of horse-keepers' wages, giving a total cost of 5·32*d.* per car-mile. It is necessary to consider, therefore, to what extent this cost can be reduced by the introduction of electrical methods. Experiments by Messrs. G. F. Sever and R. A. Fliess[1] tend to show that, on an average, 120 watt-hours per ton-mile may be taken as the maximum required, at the motor, for electric delivery-vans. It may therefore be assumed that the electrical energy required at the switchboard would be approximately one Board of Trade unit per car-mile. Including capital charges, this could be generated at less than 1¼*d.* per unit. There remains, therefore, a sum amounting to nearly 4*d.* per car-mile to bring the cost up to the figure for horse-traction; and it thus follows that if the batteries could be maintained and handled for less than that sum it would be worth while to employ electrical methods. The matter can only be decided by trial, but there seems to be a fair possibility that such a result might be reached. If maintenance in accumulator-traction on tramways can be brought down to 2*d.* per car-mile or less, it appears probable that maintenance on ordinary roads might be reduced to at least 3*d.* per car-mile, notwithstanding the bad nature of roads in parts. As automobilism increases, the roads will no doubt improve, and the maintenance will become less; but there is another possible advantage in an electrical service for omnibuses. The introduction of electric traction on tramways has proved advantageous in two ways; first, by a reduction in working cost, and second, by increased receipts on account of increased traffic. The latter is quite as important as the former. In the case of tramways the increase in receipts is frequently 30 per cent. It should be possible to run a considerably faster omnibus

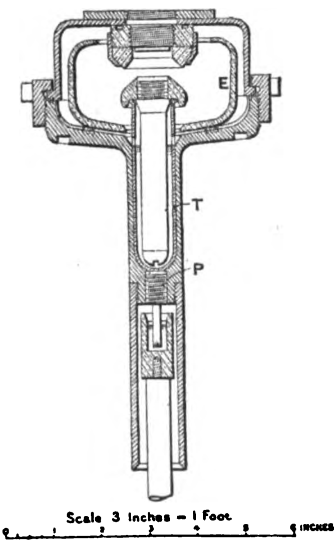
[1] Transactions of the American Inst. of Electrical Engineers, vol. xvi., 1899, p. 509.

service electrically than by horse-traction, thus securing a larger number of passengers, and at the same time increasing the number of car-miles which it is possible to run with a given capital. Even supposing so small an increase in the receipts as 5 per cent. the financial advantage would be very marked.

As avoiding the risk attending the use of batteries, it is quite possible that the Lombard Gerin system, which was shown in operation at the Paris Exhibition in 1900, may come into use where a double-trolley line is not an objection. In this system the car is connected to the trolley, which is double, by a cable instead of a pole, and the trolley runs in advance of the car, being actuated by a small three-phase motor which receives current from the direct-current motor on the car. The car is thus able to secure sufficient flexibility of movement to pass other traffic, and the advantages of trolley working are obtained without the usual heavy expenditure on track.

The Paper is accompanied by eight drawings, from which Plate 6 and the Figures in the text have been prepared; and by the following Appendix.

Fig. 13.



SECTION OF CONTACT MECHANISM.

ADDENDUM.

July, 1902.

Since the description of the Diatto system contained in the foregoing Paper was written it has been found necessary to alter the design of the contact mechanism, as shown in *Fig. 13.* The ambroin cup gave trouble through becoming hot, and any arcking caused decomposition and produced a conducting deposit on other parts. This has been overcome by introducing an earthenware cup E. Trouble was also caused by the mercury attacking the upper plug P (Fig 1, Plate 6) and slowly escaping. The ambroin tube has therefore been lined with a nickel-steel tube T, closed at the lower end, which is brazed to the plug P.

The Addendum is accompanied by a drawing, from which *Fig. 13* has been prepared.

[APPENDIX.

APPENDIX.

TABLE I.—RUNNING COSTS OF THE ACCUMULATOR LINE AT OSTEND. (PENCE PER CAR-MILE.)

—	1897	1898	1899				1900			
			July.	August.	September.	For the Season.	July.	August.	September.	For the Season.
Fuel	0·512	0·564	0·507	0·603	0·616	0·572	0·997	0·820	0·810	0·882
Oil and waste for station and cars	0·142	0·133	0·119	0·126	0·152	0·131	0·093	0·091	0·095	0·093
Wages at station (driver and switch-board attendant).	0·603	0·417	0·341	0·419	0·491	0·411	0·400	0·415	0·513	0·436
Conductors and drivers .	0·682	1·251	0·816	0·789	0·891	0·827	0·846	0·907	0·950	0·896
Track-men and maintenance of track . . .	..	0·309	0·231	0·252	0·222	0·236	0 537	0·514	0·545	0·530
Maintenance of trucks and motors	..	0·077	0·031	0·057	0·061	0·049	0·016	0·028	0·025	0·023
Handling and maintenance of batteries (excluding renewals) . .	0·597	0·278	0·104	0·107	0·134	0·114	0·113	0·117	0·158	0·127
Total . .	2·536	3·029	2·149	2·353	2·567	2·340	3·002	2·892	3·096	2·987
Car-miles run	..	17,006	8,370	8,415	6,515	23,300	7,995	7,955	5,931	21,921

TABLE II.—PARTICULARS OF ACCUMULATORS AND COSTS OF MAINTENANCE FOR VARIOUS LINES.

Name of Tramway and Authority.	Weight of Car complete with Battery.	Description of Battery.	Weight of Battery.	Life of Batteries.	Cost of Handling, Maintenance and Renewals per Car-Mile.	Remarks on the Cost.
	Tons.		Tons.			
St. Denis Tramways (Mr. Max Johannet)	16	Made by the Tramway Company	4	7,000 miles	2·46d.	
Puteaux Tramways (Tudor Company)	14	Tudor	3·4	+ plates 25,000 to 28,000 miles; − plates 15,000 to 18,700 miles	1·92d.	This is a general figure applicable to companies who do not manufacture.
Mixed traction at Hanover (Mr. Krüger)	..	Tudor	2¼	23,400 miles	0·235d. to 0·3d. for maintenance and renewals	
Ostend (Mr. de Cuyper)	13	Monobloc (chiefly)	2	..	1·07d.	
Ghent (Mr. Bayet)	13	Monobloc	2	+ plates 20,500 miles; − plates 31,000 miles	1·0d.	This figure is the cost to the Accumulator Company.
Dunkirk (Mr. Bayet)	11	Monobloc	1	..	0·485d. for renewals	This is a contract price, and is above the actual cost.
Birmingham (Mr. G. A. Grindle)	..	..	..	29,000 miles	0·45d. for renewals	This figure is the cost to the Accumulator Company.

(*Paper No. 3311.*)

"Failure in a Building Carried on Columns."

By COURTENAY THORNTON CLIFTON, M. Inst. C.E.

IN the following Paper the Author presents an investigation of the causes of partial failure in a building carried on columns, and a description of the work carried out to remedy the defects, without entering into a consideration of the many circumstances which necessitated the general arrangement of the building as originally constructed.

The building is four storeys in height. The ground, first, and second floors provide accommodation for 250, and the third floor for 200 persons. The corridor-wall of the top floor is carried by two cast-iron columns, one above the other, having a total height of 35 feet 6 inches, and transmitting a load of 58 tons to the stone base of the columns. The building is founded on a float of pozzuolana concrete, 4 feet in thickness, laid at permanent infiltration-level. This form of foundation was adopted because the excavation showed that the whole area covered by the foundations had at one time been a deep depression which, many years previously, had been filled up with earth, stones, and rubbish. The infiltration water prevented the excavation being carried any deeper to get to the virgin soil. As there are no cracks in the outer walls of the building, it may be assumed that this float of concrete is intact.

Indications of Failure.—Soon after the completion of the building, cracks appeared in the brick cross-walls of the top storey. Starting at floor-level, where this wall rests on the corridor-wall below, the cracks followed a straight line drawn from this point to the point where the ceiling meets the corridor-wall of the top storey, which is carried on the columns.

Attributed Causes of Failure.—These cracks were evidently caused by the columns settling, and on investigation it was found that the base-flanges of some of the columns were cracked. On stripping the asphalt off the stone bases these also were found to be cracked, and the failure was therefore attributed to the crushing of the

stone. It appeared also that the base-stone had been dressed hollow, which would have the effect of throwing the pressure on the outside of the base-flange, and would account for its being cracked. It was further observed that the stones were saturated with damp, which made them soft. This was the result of the water used in swabbing down the ground-floor finding its way to the stone, through the joint between the asphalt and the cast-iron column. By calculation it was found that the base-stone, which was of limestone and measured 2 feet 8 inches square by 1 foot 6 inches in depth, was overloaded, as it was exposed to a pressure of 590 lbs. per square inch, whereas ordinary samples of this stone are crushed at a pressure of 3,000 lbs. per square inch, giving a factor of safety of only 5. This explanation of the failure was not very convincing. That the stone should have crushed when only loaded to one-fifth of its laboratory crushing-strength, even although it was weakened by being saturated with damp, seemed doubtful. New stones, 3 feet 6 inches square by 1 foot 6 inches in depth, were ordered from Triest, and new columns from England. Tripod shores on wide timber bases were erected round the columns, and gypsum tell-tales showed that the movement continued. Much deliberation was given to deciding on the best means of supporting the superstructure (a load of 58 tons) while the thirteen columns and base-stones were changed. No risks could be run which would endanger the lives of between 400 and 500 people who inhabited the building. The result of this forethought was so satisfactory that during the work no change was found necessary either in the shoring or in the method of working.

General Scheme for Remedy.—The shoring consisted of a pair of A-frames set up under the girder carrying the gallery at first-floor level, Figs. 1, Plate 7. Their feet were let into timber bed-plates, 2 feet 4 inches by 1 foot 2 inches, with a tightening-wedge under each foot. These wedges were especially useful in loosening the shoring before removing it. Under the bed-plate and directly below each foot were inserted iron folding-wedges working between iron plates. The lower plates rested on a bed of cement-concrete 12 feet by 12 feet by 3 feet 6 inches in thickness. This bed of concrete was necessary to distribute the pressure, all of which came on new filling, 10 feet in depth between the concrete foundation and the bottom of this concrete. The pressure on the earth was thus reduced to less than ½ ton per square foot.

The longitudinal rolled joist (1 foot 2 inches in depth) at the first-floor level not being stiff enough to carry the weight between the A-frames when the column was removed, iron joists which bore

on the A-frames were packed in under the flanges of the saddle-piece between the upper and the lower column. Also vertical shoring with tightening-wedges was carried up to the main girder carrying the top-storey corridor-wall. The upper columns were thus relieved of their weight during the operation. All the shoring was braced across the building and tied to the main walls. To avoid vibration as much as possible in tightening up the wedges when transferring the load to the shores, two 50-ton hydraulic jacks were set up between the A-frames and the base-stones. These took the first lift. A piano wire was stretched between the main walls, touching the columns, to enable the vertical movements to be recorded.

Execution of Scheme.—On excavating to put in the cement-concrete for the first column, the cracks in the base-stone, which were little more than visible on the surface, were found to be wide enough at the bottom of the stone to allow of the insertion of the fingers of the hand up to the palm. Wrought-iron straps were quickly fixed round the stones to prevent them opening further, and shoring was erected under the longitudinal girder of the first floor at the edge of the pit. A boxing of $1\frac{1}{2}$-inch boards was made round the pit, to prevent the earth-filling from falling in while the concrete was being rammed. The concrete was allowed to set for 7 days before the shores for changing the columns were erected. When all was in place the wedges on the first and second floors were driven hard with a sledge-hammer. The jacks were then worked until a slight rise ($\frac{1}{32}$ inch to $\frac{1}{8}$ inch [1]) was observed on the wire. The iron folding-wedges under the A-frames were then driven hard. Stone-cutters with chisels then cut away 1 inch clearance under the column, which was thus left suspended by the bolts of its upper flange. The jacks were next slacked, when a drop of $\frac{3}{32}$ inch to $\frac{3}{16}$ inch [1] occurred. After a short pause to let the shores settle down to the weight, the rest of the base-stone was cleared.

Main Cause of Failure.—The main cause of the failure was then discovered. The stone had been levelled by means of wooden wedges, which were left in place, and had been grouted with pozzuolana mortar. The grouting in some cases had not even touched the underside of the stone at the centre, and in all cases the bed was found to be hollow, so that the whole weight was supported on the wedges and an outer margin of about 6 inches in width where the mortar could be rammed under with a trowel.

[1] These figures represent the maximum and minimum observations taken on the thirteen columns.

Consequently the stone had broken into four pieces. There was not much evidence of what might strictly be called crushing, and the dip of the stone in breaking and settling into the hollow gave the appearance which was attributed to faulty dressing, and accounted likewise for the flanges of the column becoming cracked.

The old base-stone having been cleared, the old column was removed, and, in order to provide clearance for getting in the new stone and column, the top course of the rubble masonry under the stone (about 6 inches in depth) was demolished. The new Triest stone base was then slung into place, by means of a lewis and differential blocks, without being set, and was left about 6 inches below its ultimate level. The new column was then slung and bolted up permanently into its place. A wrought-iron plate, 1 inch thick and planed on its upper face, was laid between the stone and the base of the column. The stone base was next raised on wooden wedges so as to leave only $\frac{3}{8}$ inch to $\frac{1}{2}$ inch clear below the column. After the stone had been levelled, a grouting basin in brick masonry in cement was built round it, at a little distance from it, the walls being 8 inches higher than the bottom of the stone, Figs. 2, Plate 7. Neat cement grout was introduced under the centre of the stone by means of a 2-inch pipe. The grout was under a head of 4 feet or 5 feet. In this manner the space under the centre of the stone ought to be as well filled as any part. By having a head on the grout a flow was established from the centre to the outside of the stone, which carried with it the air and cement scum. The basin was filled up by this means, thus throwing 8 inches head on the grout, which allowed the water in excess to rise to the surface. The horizontal portion of the pipe was not withdrawn.

Thin steel wedges were used to force the wrought-iron plate against the base-flange of the column, and the $\frac{3}{8}$-inch space under the plate was grouted with neat cement under about 4 inches head. After setting for 7 days, the wedges under the stone, as well as the steel wedges, were withdrawn, and the shoring was removed. The drop on removing the shoring varied between nothing and $\frac{3}{32}$ inch. The greatest collective drop on any column, adding all the movements together, was less than $\frac{1}{4}$ inch, the mean drop of the thirteen columns being $\frac{5}{32}$ inch and the least drop $\frac{3}{32}$ inch.

The Paper is accompanied by two drawings, from which Plate 7 has been prepared.

(*Paper No. 3324.*)

"Construction in Concrete and Reinforced Concrete."

By CHARLES FLEMING MARSH, Assoc. M. Inst. C.E.

IN pointing out the advantages to be gained by the extensive use of concrete for constructional purposes, the Author does not wish to imply that its adoption is advisable in all cases, but that many structures can be, and are, efficiently constructed of this material, with considerable saving in expenditure and little sacrifice of appearance.

Reinforced concrete is extremely economical for such structures as warehouses, goods-sheds, dock-buildings, factories, piers, wharves, covered reservoirs, water-towers, etc., where an imposing building is not required. The economy of reinforced concrete construction is due to the fact that no skilled labour is required. The iron or steel can be delivered at the works cut to the necessary lengths and bent to the required forms, and the work of building can be done by ordinary labourers, with good supervision in order that the concrete may be properly proportioned and mixed, and well consolidated around the ironwork. In general, no connections are required in the ironwork, the lengthening of the rods and other connections being accomplished by simply overlapping in the concrete, but in some systems the metallic skeleton is interwoven or tied at the intersections, and in the Bonna system a few bolts are used. Iron embedded in concrete, even although submerged in water, is practically permanent, and the expansion and contraction of iron and concrete are practically the same; as an instance bearing out the former statement, a nail, found by the Author embedded about 3 inches below the surface of the concrete apron of a weir which had been in existence for about 13 years, showed no sign of deterioration. Even rusty iron, after having been some time in concrete, becomes clean.

Self-faced concrete in any structure is certainly not imposing or beautiful, but in some positions where it is not much seen, or where the face, being frequently covered by water, is soon coated with slime or otherwise discoloured and rendered unsightly, a good and even face of concrete is much cheaper and just as serviceable

as masonry or brickwork. In such positions, if the shutterings or drums are well made and kept well greased, a fairly good and even face can be obtained by mixing the concrete rather wet, and well chopping down behind the shutterings or drums. Where a specially good face is required a sheeting of metal on the shutterings or drums can be employed. No rendering of the face should be necessary, and rendering the face of concrete-work should certainly be avoided if possible, as it is seldom satisfactory, the facing in course of time frequently becoming flaked off in places, giving a very unsightly appearance.

One of the chief objections to leaving a concrete face in situations where the temperature is subject to considerable variation is that it becomes cracked from expansion and contraction, making it appear unsightly. By dividing up the length of a retaining-wall with wood strips, about ½-inch thick, throughout the whole width and height of the wall, the cracking of the surface is in a great measure avoided.

For the bottoms and sides of service reservoirs and tanks, concrete with bituminous sheeting near its inner surface produces a thoroughly watertight and economical structure. Concrete arches of large span have been constructed both with and without hinges, but it is probably better to use hinges at the springings and centre. When a good appearance is desired, either a brick or stone-faced concrete structure combines cheapness with effect. Where brickwork is used as a face, one course of headers and three courses of stretchers are laid and allowed to set, after which concrete is filled in for the required width between the brickwork and the back of the excavation, or between the brickwork and the rough back-shuttering where the wall is above ground-level and will be subsequently backed up with earthwork; another course of headers and three more courses of stretchers are then laid, concrete is filled in again, and the process is repeated until the wall is completed to its full height. Where the facing is of stone the process is exactly similar, except that masonry of varying width is used instead of brickwork. When rubble is employed, it should not be less than about 6 inches in width, and should have an average thickness of about 9 inches. The height to which the rubble face is built before filling behind with concrete should not exceed 1 foot. A wall built in this manner, of Kentish Rag and concrete, the joints of the facing being made in the shape of a projecting V, has a very pleasing appearance as the abutments, piers, wing-walls, and spandrils of a bridge, or for retaining- or river-walls.

Thin concrete with wood strips about ½ inch in thickness

inserted at intervals of about 12 feet, to prevent cracking from expansion and contraction, is as serviceable as pitching for aprons to weirs, linings to water-channels, or along the slopes of reservoir-embankments to prevent scouring from flow or wave-action of water, and when the slope will allow of the concrete being mixed in a somewhat sloppy condition a surface can be obtained which has all the appearance of rendering, by working a straight-edge on the strips, which serve as screeds; or the same effect may be obtained by slightly wetting the surface of the concrete before screeding. Where the surface thus produced is not satisfactory a perfectly smooth surface can be obtained by patting and smoothing with the back of a shovel while still wet. It is well to sprinkle sand on the concrete when bringing to a surface, as this to a great extent prevents peeling caused by changes of temperature, and it is advisable to keep such surfaces covered with earth or other suitable material for some months after they are finished. The advantage gained in economy with this method, as compared with pitching, is obvious.

Where, for the sake of economy, concrete is decided upon as the material to be used for arched bridges, if the faces of the arches and a ring on the soffits are built of bricks, and the abutments, wing-walls, piers and spandrils are faced with brick or stone, the whole of the hearting being of concrete and the parapets and pilaster-tops of brickwork or masonry to suit the facing, a bridge can be constructed with any degree of finish, having all the appearance and stability of a bridge built entirely of brickwork or masonry, and at a very considerable saving in cost. In turning concrete arches it is well to do so in layers; each layer as it is put on will help the centering, which consequently can be made of a lighter nature than would otherwise be necessary. The use of concrete for copings, caps, and mouldings will cause a substantial saving in cost, especially in those situations where the freight charges on stone or bricks add considerably to their value. Around London the saving by the employment of concrete for ordinary straight copings made from ballast excavated on the site of the works, as compared with Derbyshire or Yorkshire stone, will amount to between 3*s.* and 3*s.* 6*d.* per cubic foot. The concrete for copings and similar purposes should be mixed in the ratio of 4 or 3 of ballast (according as there is much or little sand in the ballast), which has been passed through a screen of ½-inch mesh, to 1 of Portland cement. Concrete of stone chippings passed through a similar screen could be used equally well for those purposes, gauged 3 of stone, 2 of sand, and 1 of Portland cement.

Copings should be moulded, when possible, lying on their front face, as the chamfer is then under the greatest pressure and is consequently well formed. It is well to have a small chamfer of about $\frac{3}{4}$ inch on the top of the coping along the back edge, as in moulding there is always a slight variation in shrinkage, and the small chamfer prevents any unsightliness when the copings are backed up with earthwork. An ordinary-sized coping, cap, or other moulding can have its mould removed after 48 to 72 hours, according as the weather is dry or wet, and the mouldings should be left standing in position for about 2 days after the removal of the moulds, after which time they can be laid flat or stacked, being removed and placed in the work after a fortnight or 3 weeks from the date of moulding, according to the state of the weather. Special kneeler- or angle-copings are better left for a somewhat longer period before being placed in the work. Some special copings cannot be moulded standing on their front faces. The best position in which to mould these is with their upper surfaces downwards, and, if possible, resting on a sheet of zinc nailed to boarding.

The Author made some experiments to ascertain what loss of strength was sustained by cement-mortar gauged 3 to 1, which had been left standing for 1 hour and for 2 hours, or which had been "knocked up" at intervals of 10 minutes during those times. The results of the tests being so different from what had been expected, the experiment was repeated and extended to 5 hours. In the following Table are given the details of the experiments:—

COMPARATIVE TENSILE STRENGTHS IN LBS. PER SQUARE INCH.

Freshly mixed.	Left standing		Knocked up every 10 Minutes	
	after 1 Hour.	after 2 Hours.	after 1 Hour.	after 2 Hours.
185	186	180	186	170
226	233	231	223	236
	after 2½ Hours.	after 3 Hours.	after 2½ Hours.	after 3 Hours.
203	203	203	196	196
	after 3½ Hours.	after 4 Hours.	after 3½ Hours.	after 4 Hours.
158	146	161	163	168
	after 4½ Hours.	after 5 Hours.	after 4½ Hours.	after 5 Hours.
200	153	118	158	120

The first tests were of mortar taken from the bricklayers' own mixing, and the remainder were made from mortar specially mixed with 10 per cent. of water; the figures given are the average strengths of three briquettes. The briquettes were taken from the moulds 48 hours after moulding and were placed in water, being tested 28 days after moulding. It certainly appears that, contrary to the generally accepted notion, cement-mortar does not lose in strength to any extent by being left standing for some time, although the process of setting must have begun probably during the second half-hour. The cement used was slow-setting, the final set taking place in 5½ to 7 hours.

In recent years reinforced concrete has come more and more into use for buildings, arches, and other structures, especially on the Continent and in America; its employment in this country is, however, still far from general. The Author proposes to describe briefly one or two of the principal systems of reinforced concrete construction. For all systems of reinforced concrete the proportions and sizes of the ingredients employed should be those already recommended for concrete copings, except where water-tightness is required, when sand and cement only should be used.

The "Monier" system [1] of reinforced concrete is used principally for arches, roofs, and floors, and consists in laying a network of iron or steel rods in the lower portion of the concrete, to resist the tensile stresses produced; the rods are placed about ⅜-inch from the underside of the slab, and the joints between the rods are made by allowing them to overlap each other. The adhesion of concrete to steel has been stated to be as much as 569 lbs. to 668½ lbs. per square inch. If 584 lbs. per square inch be taken, with a factor of safety of 4, the length of overlap will be $24d$ (d being the diameter of the rod). The transverse rods are generally made of about three-quarters the diameter of the longitudinal rods, but this depends upon the relative spans. Arches in this system have generally a rise of about one-tenth to one-twelfth the span. It has been found that an arch in Portland cement-concrete will only sustain about one-fifth the load which can be borne by a similar arch constructed on the Monier system. Piles and cylinders on this system are usually sunk by the use of a water-jet, and are reinforced by longitudinal and circular or spiral rods. Pipes are also constructed in the same manner. Floors and roofs of covered circular reservoirs are strengthened by ribs with

[1] See Minutes of Proceedings Inst. C.E., vol. cxxxiii. p. 376.

network skeleton, either radial or in the form of equilateral triangles.

"Expanded metal," since its introduction, has been largely employed for many purposes, as the saving of labour by its use in place of network compensates for the additional cost of the "expanded metal." In fact, with any system of reinforced concrete, expanded metal is probably the best material for floors, roofs and arches. Where more than one sheet of expanded metal is used, continuity is obtained by slightly overlapping the sheets. A 3-inch concrete slab is sufficient for most floors, but this must necessarily vary with the span and the load to be carried. In one of the methods used in applying expanded metal to floors, the slab of concrete and expanded metal is carried on rolled joists or girders with curved channel-bars as secondary beams, the joists and channel-bars being embedded in concrete formed on expanded metal of small mesh. For ultimate loads not exceeding 1 ton per square foot the spans between the joists may be 8 feet to 18 feet, and between the channel-bars 4 feet to 7 feet. The weight of the floor need not exceed 25 lbs. to 30 lbs. per square foot, and that of the floor and supporting channel-bars 35 lbs. to 40 lbs. per square foot. Expanded metal has been found to increase the strength of concrete floors and arches from eight to eleven times. It may be advantageously employed in concrete arches, and for placing in the back of retaining-walls in doubtful ground, or in walls to resist water-pressure where for any reason the proper thickness to prevent tensile stress cannot be conveniently given, and for many other purposes.

The Hennebique system[1] of reinforced concrete is probably the most simple yet introduced; it is applied to piles, foundation-blocks, columns, uprights, beams, sills, lintels, mullions, walls, floors, cornices, roofs, etc. In fact, buildings can be constructed entirely of Hennebique reinforced concrete from the piles which may be necessary for the foundations, to the roof. Bridges of large span have been erected on this system, the roadway being carried by beams on columns resting on the arches. A reinforced concrete jetty on the Hennebique system costs much less than a similar structure in iron, is only about three times as expensive as if made of timber, and is more lasting and requires less attention than either. The fact that piles made of reinforced concrete stand driving proves that beams, etc., of these materials

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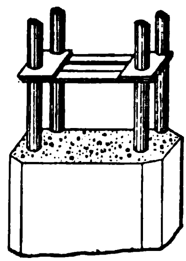
[1] See "Die Bauweise Hennebique," by Dr. W. Ritter, *Schweizerische Bauzeitung*, 1899, pp. 41, 49, and 59.

may be subjected to moving loads without damage. The square piles are formed of concrete, with a rod of mild steel in each corner about 1 inch below the surface of the concrete; the rods are bent inwards at the bottom and embedded in the shoe, which is of the ordinary construction, and are held in position by wire distance-pieces about $\frac{3}{16}$ inch in diameter, which are bent to fit loosely round the rods, to keep them at the desired distance apart. These are dropped down from the top as required, and the sets are placed about 6 inches apart. The piles are moulded in an upright position, supported in timber racks, and about 3 inches covering of concrete is allowed over the tops of the rods, although piles can be driven with the tops of the rods flush with, or even slightly above, the top of the concrete, without any shattering being produced. Piles can be made of any length, size or shape required, and should it be necessary to add to the length when the pile is driven, or to connect piles to columns, it is only necessary to break away the concrete for the required distance, insert additional bars, and mould to the desired height. The piles are driven with an iron hood-capping in which a bag of sawdust is placed. Piles constructed in this way, 14 inches by 14 inches in cross-section, have been driven by a 2-ton monkey with a drop of 6 feet, and have stood perfectly. The driving of 12 inches by 12 inches piles with a 30-cwt. monkey and a drop of 4 feet is quite usual. The piles can be driven with perfect safety 3 weeks after moulding in the summer months, but it is better to leave them for a month or 6 weeks in the spring and autumn, and if not required after that interval of time they can be taken from the rack and stacked lying down until required. Groups of piles driven to carry columns have the concrete at the top of the piles broken away for the required distance when driven to the necessary depth; the rods of the column are then placed so as to overlap the rods of the piles and the concreting of the column is commenced. The columns and uprights (*Fig. 1*) are formed in much the same manner as the piles, but are generally moulded in position; the wire or flat iron cross-pieces need not be so close together as in the piles, being usually about 1 foot 3 inches apart. The rods of the columns terminate at the bottom just above a steel plate which is embedded in the upper part of the foundation-block,

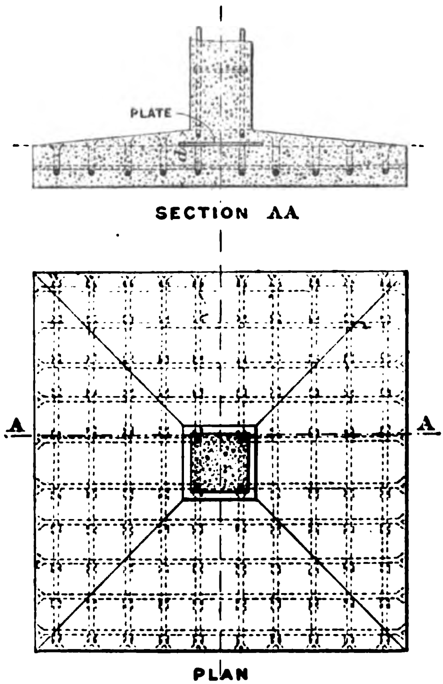
Fig. 1.



CONSTRUCTION OF HENNEBIQUE COLUMN.

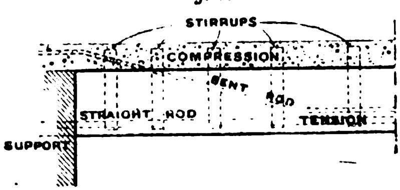
Figs. 2. The foundation-blocks are formed of concrete, with steel bars crossing at right angles, the bottom rods being supported by U-shaped hoop-iron stirrups, having the arms bent out slightly at the top. The stirrups (which are employed to resist shearing) are always brought up to just under the surface of the concrete. In the beams there are usually two series of rods; the rods of one set are bent in the form of a truss having the central horizontal portion and each inclined portion of the same length horizontally, each being not quite one-third of the span, and the top bends being made a short distance from the supports; the rods of the other set are straight, and are laid along the bottom of the beam, with about 1 inch covering of concrete, *Fig.* 3. Sometimes compression-bars are used in the upper portion of the concrete, a less depth of beam being then sufficient. The straight bottom-bars are supported by stirrups (*Fig.* 4), which are spaced farther apart as the centre of the beam is approached, *Fig.* 3. The depth of the beams is generally one-twelfth to one-fifteenth of the span. Lintels, sills, mullions, and lesser uprights for window- and door-frames, and to form the bays of the face, are generally moulded before fixing, the rods being fitted with cross distance-pieces of wire in the same manner as

Figs. 2.



HENNEBIQUE FOUNDATION-BLOCK.

Fig. 3.

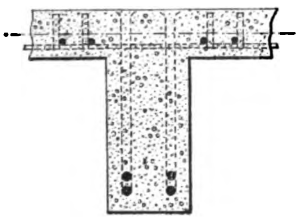


HENNEBIQUE BEAM.

described for the columns. These can be chamfered and rebated as desired, and the rods placed accordingly.

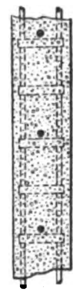
The floors are formed of concrete with bars crossed at right angles in the lower portion of the concrete, and with about ½ inch covering of concrete, *Fig. 5.* The lower bars are supported by stirrups for some distance from the beams, in the same manner as the bars in the beams; but stirrups are not necessary for some distance on each side of the centre of the floor. The rods of the columns are continued up into the beams. The tops of the stirrups of the beams terminate just below the upper surface of the floor-slab, and the bent bars of the beams are generally taken into the floor-slab. The bays of the outer walls can be filled in with concrete and rods, or with a filling of concrete, brickwork, or masonry, between the lesser uprights and lintels as desired. Partition-walls, and sometimes exterior walls, are formed with vertical and longitudinal rods, the vertical rods being staggered and connected to the further face of the wall by stirrups. The longitudinal rods are placed in the centre of the wall, *Figs. 6.*

Fig. 4.

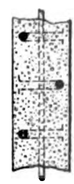


SECTION OF HENNEBIQUE BEAM.

Figs. 6.



SECTIONAL ELEVATION



SECTIONAL PLAN

HENNEBIQUE WALL.

Fig. 5.

SECTION OF HENNEBIQUE FLOOR.

If the pressure is only on one side of the wall, as in a retaining-wall, the vertical rods are only placed on the side against which the pressure acts.

Some tests for deflection and vibration were made by the Orleans Railway Company on a Hennebique floor having the following dimensions:—

	Feet.	Inches.
Depth of slab	0	3½
„ from bottom of slab to bottom of primary beams	1	0
„ „ „ „ secondary „	0	8
Width of primary beams	0	8
„ secondary „	0	6
Span of primary beams	16	0
Distance apart, centre to centre, of primary beams	7	5

The weight of the entire floor was about 61 lbs. per square foot. This floor showed a deflection of 0·143 inch under a dead load of 430 lbs. per square foot. The same floor was also tested for impact against a floor supported on rolled joists and jack-arches of the following dimensions:—

Rolled joists	10 inches by 6 inches.
Span	15 feet.
Distance apart centre to centre	2 feet 3 inches.
Thickness of floor-slab above top of joists	2 inches.
Depth of jack-arches at centre	8 „

The weight of this floor was about 98·3 lbs. per square foot. The Hennebique floor, subjected to the impact of a weight of 220 lbs. falling from a height of 13 feet, or 2,860 foot-lbs., suffered a vertical deflection of 0·047 inch, and the duration of the vibrations was $\frac{4}{5}$ second. The floor of rolled joists and jack-arches, subjected to the impact of a weight of 110 lbs. falling 6 feet 6 inches, or 715 foot-lbs., suffered a vertical deflection of 0·28 inch, the duration of the vibrations being 2 seconds.

Prices of reinforced concrete vary so much, depending as they do on the cost of materials and labour, that it is impossible to give prices which can be applied generally. The Author gives below some costs for this system, but these must be looked upon as only approximate.

At Calais Docks the roof of a single-storey warehouse, including columns and beams, cost about 1*s.* 11*d.* per square foot.

A two-storey grain warehouse at Plymouth, having a load on the floors of 5 cwt. per superficial foot, cost, exclusive of the pile foundations, 4*d.* per cubic foot of air-space.

In one instance the following were the costs of different items:—

Roof	1*s.* 4*d.* per square foot.
Floors, including beams	2*s.* 1*d.* „ „ „
Internal columns	9*s.* 1*d.* „ lineal „
External „	5*s.* 9*d.* „ „ „
Piles, 10 inches by 10 inches	5*s.* 6*d.* „ „ „
„ 16 „ „ 16 „	9*s.* 3*d.* „ „ „

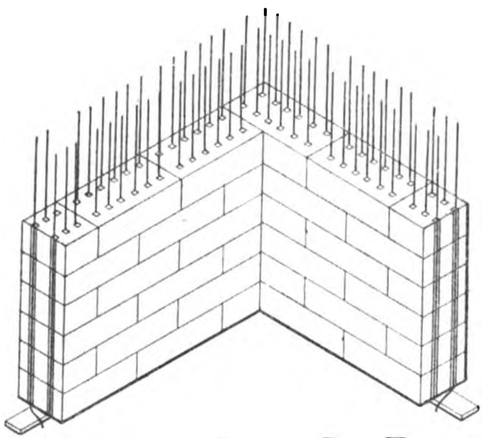
The Cottançin system of reinforced concrete and brickwork is one of the oldest, and is extensively used in France for buildings, reservoirs, bridges, sewers, etc. It does not appear so simple in construction as the Hennebique system, as it consists generally of a woven core of metal carried up through the foundations, walls, floors, roofs, etc., of the structure, forming a continuous network throughout the whole structure. The mesh consists of longitudinal and transverse wires interwoven after the manner of basket-work.

Special machinery has recently been devised for weaving the network for floors, etc. Foundations of the inverted box-type, with cellular compartments, are a feature of this system, and are built of concrete or brickwork reinforced with Cottançin network; they are very useful for treacherous foundations, and where the non-transmission of vibration from machinery is a desideratum. As an instance, the experiments carried out by engineers of the Ponts et Chaussées at Tunis to determine the most suitable form of foundations to extend the town on the silt-covered area of the ancient lake may be mentioned. Ordinary foundations were found incapable of supporting a load exceeding 32 lbs. per square foot without irregular settlement, while those of the inverted box-type on the Cottançin system bore a load of 777 lbs. per square foot, with a uniform subsidence of 0·08 inch, and on increasing the load to 1,711 lbs. per square foot the settlement was still uniform, being about $1\frac{3}{16}$ inch.

Cottançin walls and columns are generally constructed of brickwork, the bricks having vertical perforations through which pass the wires, which are twisted round horizontal flat bars along the top and bottom bed-joints, and also where connections are required for floor-network, the bricks being set and the perforations grouted with cement mortar. Sometimes horizontal wires are used at the bed-joints, interwoven with the vertical wires. Outer walls of houses of five or six storeys have been constructed by using double cellular walls of such bricks, each wall being only about $2\frac{3}{8}$ inches thick. The bricks generally used are about $8\frac{5}{8}$ inches by $2\frac{3}{8}$ inches by $3\frac{1}{8}$ inches, and have one row of four perforations $1\frac{3}{16}$ inch square to each brick when laid flat. Bricks of double width, with two rows of four or more perforations, are sometimes used, but the special narrow brick is used both for partitions and outer walls on the double cellular system. The cellular walls have vertical cored cross-walls carried up between the main walls for the whole height. The walls of the church of St. Jean de Montmartre in Paris, built on this system, are 115 feet in height and only about $4\frac{1}{2}$ inches in thickness, and the columns for the same church are only about 1 foot $5\frac{3}{4}$ inches square in cross-section. The walls are stiffened with counterforts 1 foot $5\frac{3}{4}$ inches square, and the whole edifice is reinforced with Cottançin network, and is surmounted by domes. A dome 52 feet in diameter and 125 feet above the ground-level, for a country residence, has been built on the Cottançin system, supported on steel-cored brick columns 1 foot $5\frac{3}{4}$ inches square. For both partition and other walls concrete is sometimes employed instead of, or in conjunction with, brickwork. The construction of a Cottançin brick-wall is illustrated in *Fig. 7*.

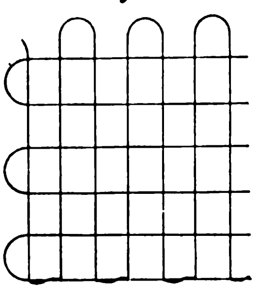
Floors and ceilings are supported by beams or ribs of concrete with imbedded network (*Fig. 8*) placed vertically and interwoven with the network of the floor and walls. The beams are usually 1 foot 2 inches in depth, and 2 inches to 4 inches in width. Beams 14 inches by 4 inches in cross-section have been employed to support floors of 39 feet 6 inches span. The beams are first formed intersecting one another, as shown in *Figs. 9*, some parallel to the walls and some diagonal, and these are often provided with nosed projections moulded along their under surfaces to support the ceiling-slabs, to form hollow floors. The ceiling-slabs are moulded before erection, and are first propped up from the projections of the beams so as to form centering for the concrete flooring, or in the alternative ordinary shuttering is provided. The network core for this flooring is then either formed *in situ*, or added ready prepared, and is interwoven with or attached to the loops left on the network of the beams and walls, *Fig. 8*. The concrete is then deposited in place, and after this has set the ceiling-slabs are lowered on to the beam projections to form the ceiling, or the shuttering is struck, and the floors are then complete with the exception of plastering to the ceiling and rendering, etc., to the floor, if the latter is required. When ceiling-slabs are used, they are of course suitably prepared on the top side, to prevent the concrete of the floor adhering to them. Floors and roofs are generally 2 inches in thickness, the network being placed about 1 inch above the underside of the slab at the sides, but, being woven before the concrete is put in, the core has a slight

Fig. 7.



CONSTRUCTION OF COTTANÇIN BRICK-WALL.

Fig. 8.

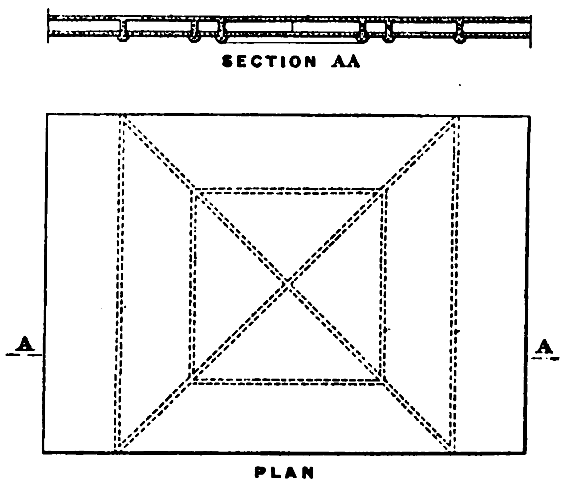


COTTANÇIN NETWORK.

sag towards the centre of the span, which sensibly adds to the strength of the slab.

Arched roofs of small rise have the roof and ceiling-slabs supported on curved and longitudinal intersecting beams, the arrangement of which may be such as to present a very pleasing appearance. Two of the methods of arranging these beams are illustrated in *Figs. 10.* Very little rise is given to the beams; in one case a 46-foot span has been put in with only 14 inches rise, and another roof, of 59 feet span, has a rise of only 16 inches. Arched beams or ribs are often made of cored brickwork. Beams are frequently made on the ground and lifted bodily into place,

Figs. 9.



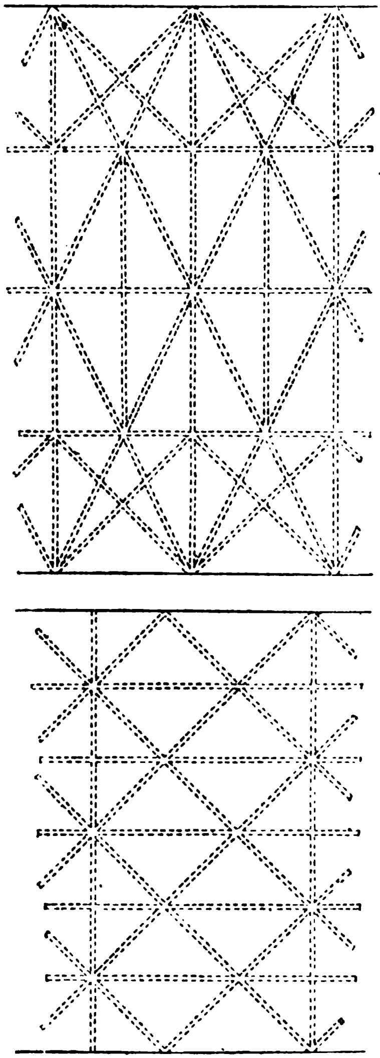
COTTANÇIN FLOOR.

their intersections being made good after they are in position. Bridges on the Cottançin system are constructed with flooring-slabs supported on longitudinal and intersecting beams, as in the case of roofs or floors. A building on this system at the Paris Exhibition of 1900 cost only about 1·7*d.* per cubic foot of air-space, being about the cost of a timber building of good quality, but this is of course exceptional. This building was successfully subjected to very exceptional tests of stability both during construction and in demolition.

Tests carried out by the French War Office and by committees of the Ponts et Chaussées have proved that great strength is obtained by this system. In one case two slabs were tested, one of cored, and

the other of plain concrete, the concrete being from the same mixing. Each slab was about 3 feet $3\frac{3}{8}$ inches square in the clear, and about $1\frac{3}{4}$ inch in thickness. The cored slab bore a distributed load of $2\frac{3}{4}$ tons, with about $\frac{1}{2}$ inch deflection, before giving way. The plain slab broke suddenly with a distributed load of little more than $\frac{1}{2}$ ton.

Figs. 10.



ARRANGEMENTS OF COTTANÇIN BEAMS FOR ARCHED ROOFS.

The Bonna system of reinforced concrete is used for pipes, buildings, reservoirs, bridges, etc. In this system, when used for buildings, the metal skeleton is erected complete before the concrete is added. It differs from most other systems in the employment of rolled sections, generally in the form of a cross. The framework is of a light character, and is connected by a small number of bolts to hold it together until the concrete is in place. The sizes of the cruciform sections generally employed range between about $\frac{1}{4}$ inch by $\frac{1}{4}$ inch by $\frac{1}{24}$ inch and about $1\frac{1}{2}$ inch by $\frac{5}{8}$ inch by $\frac{1}{8}$ inch, weighing 0·075 lb. to 1·125 lb. per lineal foot. For heavy loads, sections as large as $1\frac{1}{4}$ inch by $1\frac{1}{4}$ inch to $1\frac{1}{2}$ inch by $1\frac{1}{2}$ inch are used. Tubular sections formed of four angle-bars connected by plates are also sometimes employed. For pipes and circular tanks on the Bonna system longitudinal and spiral rods of the cruciform section are used, and for high pressures the pipes have an interior lining of thin steel. These inner tubes are

connected by collars in the same manner as cast-iron pipes, with here and there a collar-joint with packing-rings of rubber or other material to allow for expansion. Sometimes two series of longitudinal and spiral rods are used. Pipe-connections are made by cutting away the concrete and rods where required, leaving a flat surface on which a flanged cast-iron connection is placed, having a joint formed by a washer of leather or other suitable substance. The branch is secured in position by means of ring-bolts passing round the concrete pipe. A tunnel constructed on this system for the drainage of Paris has an elliptical arch, curved side-walls, and flat-dished invert, and measures 16 feet 11 inches in width and 11 feet in height, the rise being 6 feet 7 inches. The metallic skeleton has two series of rods 4¼ inches apart, one set longitudinal, ¾ inch in diameter, and the other set, following the curves of the side-walls and arch, being ⅝ inch in diameter. The concrete of the arch is 3⅛ inches in thickness and the invert is of concrete without a metallic core. In the Ransome system, square rods, twisted slightly, are used, and in the Thatcher system flat steel bars with projecting rivet-heads are employed. Both the twisting of the rods and the projecting rivet-heads are intended to prevent slipping of the metal in the concrete, which does not seem a necessary requirement. A high chimney-shaft has recently been built on the Ransome system in the United States, and an important three-way bridge at the confluence of two rivers has been built on the Thatcher system at Zanesville, Ohio, U.S.A., the spans being elliptical and of small rise. The greatest spans are 122 feet, and the least rise is about one-sixteenth of the span. The thickness of the arches at the crown varies between 18 inches for an 81-foot span and 30 inches for the 122-foot span. In the Hyatt system flat perforated plates are placed vertically in the concrete, and round rods are threaded through the perforations.

In the Wayss system, for partition-walls the horizontal rods of a network are bent upwards at the centre, forming curves, with the object of increasing the strength. The Bordenave system is very similar to the Monier, excepting that rods of I, U and L sections are used. The Melan system, in which the I section is used, is largely employed in the United States, where bridges and other structures have been built of this form of construction. A notable instance is a bridge the largest span of which is 125 feet 3 inches, and the distance from centre to centre of the piers 138 feet 6 inches, this distance being also the span of the reinforcing skeleton. The rise is one-fifth of the span. The thickness

of the arch is 1 foot 8 inches for a distance of 42 feet 6 inches on each side of the centre, increasing from these points to a thickness of 8 feet 3 inches at the springings. The metallic reinforcement is in the form of arched lattice-girders formed of angle-bars 3 inches by 3 inches, with top and bottom chords 8 inches in width.

In every system of reinforced concrete or brickwork construction where metal is introduced to resist the tensile stresses, the concrete or mortar has still also to resist these stresses, and must not be subjected to a stress beyond its ultimate resistance, which may be taken as 450 lbs. per square inch for reinforced concrete or mortar. If the concrete or mortar is strained too far it will become fractured, although the slab may still bear the load. It must be also borne in mind that since the modulus of elasticity of iron bears to that of concrete the ratio of about 10 to 1, there must be at least ten times the sectional area of concrete as of iron in order that the strain may be uniform throughout. The corresponding ratio for steel and concrete is about 12 to 1.

In conclusion, the Author desires to express his indebtedness to Mr. Ravin, Ingénieur du Chambre de Commerce, Calais, for information with regard to the Hennebique system of reinforced concrete.

The Paper is accompanied by two tracings, from which the Figures in the text, which are diagrammatic only, and not to scale, have been prepared.

(*Students' Paper No. 472.*)[1]

"The Theory of Cast-Iron Beams."

By Edward Vincent Clark, B.Sc., Stud. Inst. C.E.

That a cast-iron beam will bear a much greater load than that which, according to the ordinary theory of beams, should produce fracture, is well known; and an empirical coefficient, ranging between about 1·5 and 2·2, has invariably to be introduced into calculations in order to foretell, with any degree of accuracy, the breaking-load of such a beam. In the following Paper the Author endeavours to show that the great discrepancy between theory and experiment is not to be attributed to errors in the theory itself, but is rather due to various approximations made in its application to such a material as cast iron.

The ordinary theory of beams requires for its foundation that the material experimented on obey Hooke's law to all intensities of stress, and that its modulus of elasticity be the same for compressional as for tensional stresses (or, graphically, that its stress-strain curves form a continuous straight line passing through the origin of co-ordinates); and also that it be perfectly homogeneous throughout. None of these conditions is fully complied with by cast iron, and each of the errors thus introduced has the effect of making the apparent (calculated) strength of the beam too low. The lack of homogeneity in the material must result in all tension-tests giving a lower apparent ultimate strength than that of the average section of the material, since the specimen will naturally break at its weakest point, and in a faulty test-piece the strength at this point may be considerably below the average strength. On the other hand, in a beam the maximum bending-moment exists only at the centre of the specimen, and in this neighbourhood fracture must occur. Thus it is evident that, assuming a perfectly sound beam-theory, the calculated breaking-load for a beam, as deduced from the material's ultimate strength in direct

[1] This Paper was read and discussed before a Meeting of Students of the Institution on 19 April, 1901.

tension, will almost certainly be too low. Again, according to the ordinary theory, at any section of a beam the strain in any fibre of metal is proportional to its distance from the neutral axis; and therefore, assuming Hooke's law to be strictly obeyed, so also is the stress. But cast iron does not follow Hooke's law, and a high intensity of strain does not necessitate a proportionately high intensity of stress. It therefore follows that, with a definite limiting strain and stress in the outer tensile fibres of the section, the inner fibres, which are strained proportionately to their respective distances from the neutral axis, are stressed to a higher degree than this, and therefore have a higher moment of resistance than that assigned to them by the theory. Moreover, if the stress-strain curves for tension and for compression are not similar, the neutral axis will no longer remain central, but, in a cast-iron beam, will shift slightly towards the compression side. This increases the area under tension, and hence the sum of all the tensile stresses, and thus raises the strength of the beam to resist fracture. If the exact forms of these two stress-strain curves were known, it would be possible (on the assumption that the strain is proportional to the distance from the neutral axis) to determine the intensity of stress at any point of the section, and thence the moment of resistance of the beam. The problem is slightly complicated by the shifting of the neutral axis, but the position of this can be found from the necessary condition that the algebraic sum of all the longitudinal stresses is zero.

The object of the experiments to be described was to determine as accurately as possible the forms of the stress-strain curves for cast iron (of a particular quality); to deduce from these the position of the neutral axis and the ultimate moment of resistance of beams of certain types of cross-section; and to compare these calculated moments of resistance with the actual breaking-moments, as found by direct experiment, of similar beams of this quality of cast iron.

Fifteen bars of cast iron were obtained, all cast from one ladle, to insure as far as possible uniformity of constitution. Six of these were of the usual form for tension or compression tests, and the remaining nine, comprising three bars of each of three sections, viz., rectangular, square-on-angle, and circular, were for breaking under a bending-load.

Tension and Compression Tests.—The specimens were turned down to suitable sizes, and were submitted to test in the usual manner. The load was applied in steps of 2,000 lbs. per square inch of section, and was never removed after being once applied, no read-

ings of permanent set being taken. Strain was measured by a Kennedy extensometer, and in tension-experiments readings were taken right up to the point of fracture, the bars being broken with the extensometer-gear attached. In each of the three bars the point of rupture was outside the length on which strain was being read, but, as there is no local contraction of cross-section in the case of cast iron, this is quite immaterial. In compression-tests, strain was read up to loads of 38,000 lbs. per square inch. No measurements of ultimate crushing-stress were made, as a symmetrical beam of cast iron will invariably yield from the tension side. The three best bars were selected for tensile tests, and in each case the fractured section was perfectly sound, without sign of flaw or blow-hole. The compression pieces were not quite so good, but the few small defects could have had no appreciable effect on the measurements of strain, which were made upon a length of 10 inches. In Tables I. and II. are given the results of the experiments on tension and on compression, while in *Figs. 1* and *2* the corresponding curves are plotted.

In both tension and compression, the relation between stress and strain is seen from the Tables and from the plotted curves (*Figs. 1* and *2*), to be very closely represented by a parabolic curve. Expressing stress as a function of strain, the equations to the curves are:

$$y = 1690\,x - 24\,x^2 \text{ for tension.}$$
$$y = 1690\,x - 7\,x^2 \text{ for compression.}$$

Where y = stress in lbs. per square inch.
x = strain in thousandths of an inch upon a length of 10 inches—*i.e.*, in hundredths per cent.

From these equations it is evident that both tension and compression stress-strain curves have the same tangent at the origin—that is, the same initial slope; and as the coefficients of x^2 are small, it follows that for small values of strain it is a close approximation to ignore the second terms of the equations and to represent both tension and compression stress-strain curves by the equation $y = 1690\,x$. That is, for low stresses, cast iron does fulfil very closely the two conditions as to stress and strain on which the ordinary theory of beams is built up. But the equations also show that at higher stresses both these conditions fail to hold, that each curve deviates considerably from its initial tangent, and the tension-curve much more rapidly than the compression-curve.

It will be seen that the coefficient of x gives the initial modulus of elasticity of cast iron, and, expressed in the usual units, this is

16,900,000 lbs. per square inch for both tension and compression. It should be observed, however, that the deviation of the compression-curve from a straight line is so slight that the inevitable errors of observation somewhat obscure the curve's true shape. The curve $y = 1710\ x - 7 \cdot 8\ x^2$ agrees with the mean experimental

TABLE I.—CAST IRON IN TENSION.

Stress. Lbs. per Square Inch.	Strain. Thousandths of an Inch on 10 Inches.				
	Bar No. 1.	Bar No. 2.	Bar No. 3.	Mean.	From Equation.
2,000	0·8	0·9	0·8	0·8	1·2
4,000	2·1	2·1	2·2	2·1	2·5
6,000	3·4	3·5	3·5	3·5	3·8
8,000	4·8	4·9	4·9	4·9	5·1
10,000	6·3	6·3	6·3	6·3	6·5
12,000	7·9	7·9	7·8	7·9	8·0
14,000	9·6	9·5	9·3	9·5	9·6
16,000	11·4	11·3	11·1	11·3	11·3
18,000	13·3	13·2	12·9	13·1	13·1
20,000	15·7	15·2	14·7	15·2	15·0
22,000	17·9	17·7	17·0	17·5	17·2
24,000	20·2	20·0	19·3	19·8	19·7
26,000	23·4	23·0	22·0	22·8	22·7
28,000	..	26·1	25·0	..	26·6
30,000	..	..	28·7	..	..
Stress at fracture	27,100 lbs. per square inch.	28,900 lbs. per square inch.	31,500 lbs. per square inch.	Mean—29,170 lbs. per square inch.	..

The sixth column gives calculated values of strain, deduced from the equation $y = 1{,}690\ x - 24\ x^2$,
where y = stress in lbs. per square inch,
x = strain in mils on 10 inches.

Diameter of bar No. 1 . . . . 0·677 inch.
" " " " 2 . . . . 0·729 "
" " " " 3 . . . . 0·571 "

points to about the same degree of accuracy as does the equation already given, and it would be necessary to carry measurements of strain to a considerably higher point to determine which of the two is the more accurate. But the difference between these two parabolic curves, in the lower regions of stress, is too slight to

have any appreciable effect upon the calculations for strength of beams.

The equation to the tension-curve, $y = 1690\,x - 24\,x^2$, represents a parabola having its axis vertical—*i.e*, parallel to the axis of stress, and consequently, if the curve be prolonged, it will reach a

TABLE II.—CAST IRON IN COMPRESSION.

Stress. Lbs. per Square Inch.	Strain. Thousandths of an Inch on 10 Inches.				
	Bar No. 1.	Bar No. 2.	Bar No. 3.	Mean.	From Equation.
2,000	1·0	1·1	1·0	1·0	1·2
4,000	2·1	2·3	2·7	2·35	2·4
6,000	3·2	3·6	4·0	3·6	3·6
8,000	4·3	4·8	5·3	4·8	4·8
10,000	5·4	5·8	6·7	6·0	6·05
12,000	6·8	7·2	7·9	7·3	7·3
14,000	8·0	8·6	9·1	8·6	8·6
16,000	9·4	9·8	10·3	9·8	9·85
18,000	10·5	11·1	11·7	11·1	11·15
20,000	11·7	12·6	12·9	12·4	12·5
22,000	13·0	13·8	14·3	13·7	13·8
24,000	14·3	15·2	15·7	15·1	15·15
26,000	15·6	16·9	16·9	16·5	16·5
28,000	17·0	18·1	18·3	17·8	17·9
30,000	18·4	19·4	19·7	19·2	19·3
32,000	19·7	20·9	21·2	20·6	20·7
34,000	21·1	22·4	22·6	22·0	22·15
36,000	22·6	24·0	24·3	23·6	23·6
38,000	..	25·6	25·8	(25·2)	25·1

The sixth column gives calculated values of strain, deduced from the equation $y = 1{,}690\,x - 7\,x^2$,
where y = stress in lbs. per square inch,
x = strain in mils on 10 inches.

Diameter of bar No. 1 . . . . 0·710 inch
„ „ „ „ 2 . . . . 0·612 „
„ „ „ „ 3 . . . . 0·684 „

maximum ordinate of stress at the vertex of the parabola. This maximum ordinate represents a stress of 29,750 lbs. per square inch, and the corresponding abscissa of strain is 35·2 thousandths of an inch. But the mean breaking-strength of the three test-bars was 29,170 lbs., or within 2 per cent. of this theoretical maximum

value. Therefore, having regard to the fact that, while the bar

Fig. 1.

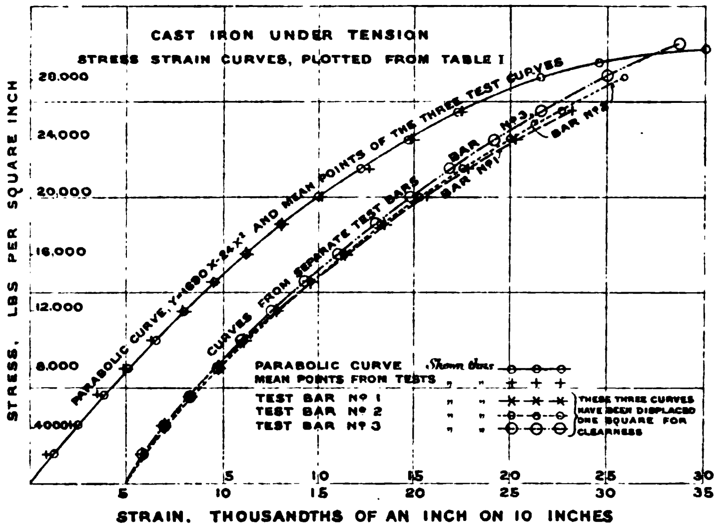
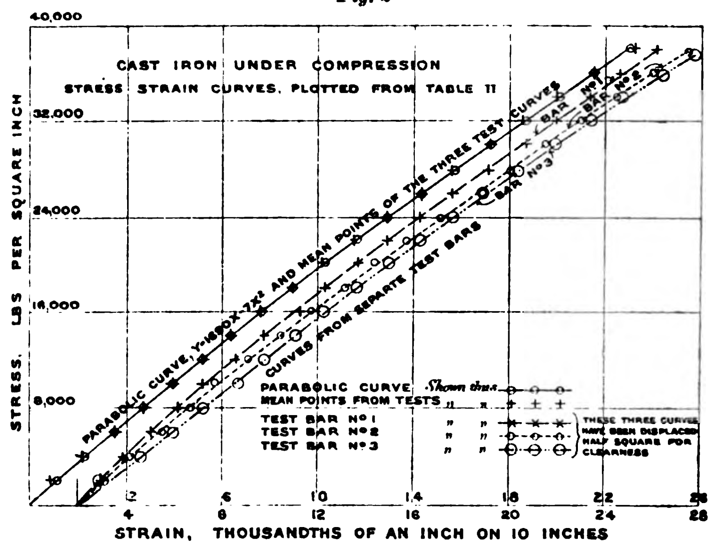


Fig. 2



breaks at its point of minimum strength, the strain, as measured, is the average extension over a certain length—10 inches in this

case—it is not unreasonable to assume that this maximum ordinate, 29,750 lbs. per square inch, and the corresponding abscissa, 35·2 thousandths of an inch, are the average limiting values of stress and strain; and in all calculations these values, deduced from the equation, have been taken as the true average breaking strength and strain for this quality of cast iron, the excess of 2 per cent. in the value of this stress over the observed mean breaking-load being the allowance made to place bending experiments on the same footing as those of tension, on account of the want of homogeneity of the material. This allowance can hardly be considered excessive, since the variation of strength between the three test-bars, which were all of one metal, and cast simultaneously, amounted to no less than 15 per cent, or $7\frac{1}{2}$ per cent. above and below the average.

The equations thus obtained for tension and compression stress-strain curves may be readily applied to the theory of beams, and yield expressions which give the position of the neutral axis and the modulus of resistance for any particular type of section. The evaluation of these expressions, however, is not always easy. In the following investigations for beams of rectangular, square-on-angle, and circular sections, in order that results may be general, calculations are made with the parabolic formulas

$$y = \alpha x - \beta x^2 \text{ for tension,}$$

and

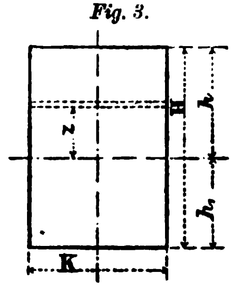
$$y = \alpha_1 x - \beta_1 x^2 \text{ for compression:}$$

and the particular values of these constants for the cast iron employed in the experiments are afterwards interpolated.

Determination of the Neutral Axis and Modulus of Section of Beams: Let P represent the maximum tensile strain of the metal.

Case I.—Beam of rectangular section (*Fig. 3*). Total depth, H; breadth, K:—

Fig. 3.



If the stress-strain curves of tension and compression are different, the neutral axis will not be central. Its position is determined by the fact that the algebraic sum of all forces normal to the section is zero.

Let the neutral axis be distant h from the top (tension side), and h_1 from the lower side of the beam.

Strain being proportional to distance from the neutral axis, the strain at a distance z from it, on either the tension- or the compression-side, will therefore be $P\frac{z}{h}$, since P is the strain in the outer tensile fibre, distant h from the neutral

axis. The argument is the same, and the resulting equations hold good, whether P is taken as the maximum tensile strain the metal can bear, or as the strain in the outer fibre produced by any definite load.

On the tension side, the intensity of stress at this point is:—

$$\alpha\, P \frac{z}{h} - \beta\, P^2 \frac{z^2}{h^2}$$

The whole tensile force over the elementary strip is—

$$\left\{\alpha\, P \frac{z}{h} - \beta\, P^2 \frac{z^2}{h^2}\right\} K\, d\, z;$$

and the total force over the tension area of the section is—

$$\int_0^h K \left(\alpha\, P \frac{z}{h} - \beta\, P^2 \frac{z^2}{h^2}\right) d\, z.$$

On the compression side, the intensity of stress on the elementary strip is—

$$\alpha_1 P \frac{z}{h} - \beta_1 P^2 \frac{z^2}{h^2};$$

and the total force over the whole compression area is—

$$\int_0^{h_1} \left(\alpha_1\, P \frac{z}{h} - \beta_1 P^2 \frac{z^2}{h^2}\right) K\, d\, z.$$

As the tension and compression forces must be equal, these two integrals must be equal.

That is $\quad \dfrac{\alpha K P h^2}{2\, h} - \dfrac{\beta K P^2 h^3}{3\, h^2} = \dfrac{\alpha_1 K P h_1{}^2}{2\, h} - \dfrac{\beta_1 K P^2 h_1{}^3}{3\, h^2};$

which reduces to—

$$\tfrac{1}{2}\left(\alpha\, h^2 - \alpha_1\, h_1{}^2\right) = \frac{P}{3\, h}\left(\beta\, h^3 - \beta_1\, h_1{}^3\right)$$

whence, as $h_1 = H - h$, the position of the neutral axis may be found.

To express the amount of shifting of the neutral axis as a percentage of the beam's total depth, let—

$$h = m\, H. \quad h_1 = (1 - m)\, H, = m_1\, H;$$

when the equation becomes—

$$\tfrac{1}{2}\left(\alpha\, m^2 - \alpha_1\, m_1{}^2\right) = \frac{P}{3\, m}\left(\beta\, m^3 - \beta_1\, m_1{}^3\right).$$

With regard to strength to resist bending, the moments of the

elementary strips on the tension and compression sides about the neutral axis are respectively—

$$K\left(\alpha P\frac{z}{h} - \beta P^2\frac{z^2}{h^2}\right) z\,dz, \text{ and } K\left(\alpha_1 P\frac{z}{h} - \beta_1 P^2\frac{z^2}{h^2}\right) z\,dz.$$

The total moments of the two sides are respectively the integrals of these, taken from the neutral axis to the edge of the beam—

$$i.e. \int_0^h K\left(\alpha P\frac{z}{h} - \beta P^2\frac{z^2}{h^2}\right) z\,dz, \text{ and } \int_0^{h_1} K\left(\alpha_1 P\frac{z}{h} - \beta_1 P^2\frac{z^2}{h^2}\right) z\,dz,$$

and the sum of these two gives the moment of resistance of the beam, which is therefore—

$$\frac{\alpha K P h^3}{3h} - \frac{\beta K P^2 h^4}{4h^2} + \frac{\alpha_1 K P h_1^3}{3h} - \frac{\beta_1 K P^2 h_1^4}{4h^2},$$

which reduces to—

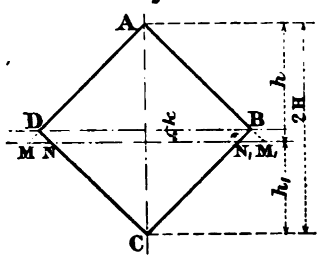
$$\frac{KP}{3h}(\alpha h^3 + \alpha_1 h_1^3) - \frac{KP^2}{4h^2}(\beta h^4 + \beta_1 h_1^4).$$

Expressing this in terms of the beam's dimensions, and the percentage shifting of the neutral axis from the position of symmetry, *i.e.*, putting $h = m H$, and $h_1 = (1 - m) H = m_1 H$:— Internal moment of resistance

$$= K H^2 \left\{\frac{P}{3m}(\alpha m^3 + \alpha_1 m_1^3) - \frac{P^2}{4m^2}(\beta m^4 + \beta_1 m_1^4)\right\}.$$

Case II.—Beam of square-on-angle section (*Fig. 4*). Total depth $2H$ (*i.e.*, semi-diagonal $= H$) :— Let the neutral axis be distant h from the upper (tension) and h_1 from the lower (compression) side of the beam. And let the displacement of the neutral axis from the horizontal diagonal be k. Then $h = H + k$, $h_1 = H - k$, and $h + h_1 = 2H$.

Fig. 4.



The tension side of the beam may be considered as the difference between the triangle $M A M_1$, and the two small triangles $M D N$ and $M_1 B N_1$, while the compression side is the triangle $N C N_1$.

The following results may be easily obtained :—

From the condition of equilibrium—

$$\int_o^h 2\,(h-z)\left(a\,P\frac{z}{h}-\beta\,P^2\frac{z^2}{h^2}\right)dz - 2\int_o^k 2\,(k-z)\left(a\,P\frac{z}{h}-\beta\,P^2\frac{z^2}{h^2}\right)dz$$
$$= \int_o^{h_1} 2\,(h_1-z)\left(a_1\,P\frac{z}{h}-\beta_1\,P^2\frac{z^2}{h^2}\right)dz.$$

Whence—

$$a\,(h^3-2\,k^3)-a_1\,h_1^3 = \frac{P}{2\,h}\,\{\beta\,(h^4-2\,k^4)-\beta_1\,h_1^4\}$$

and moment of resistance

$$= \int_o^h 2\,(h-z)\left(a\,P\frac{z}{h}-\beta P^2\frac{z^2}{h^2}\right)z\,dz - 2\int_o^k 2\,(k-z)\left(a\,P\frac{z}{h}-\beta P^2\frac{z^2}{h^2}\right)z\,dz$$
$$+\int_o^{h_1} 2\,(h_1-z)\left(a_1\,P\frac{z}{h}-\beta_1\,P^2\frac{z^2}{h^2}\right)z\,dz,$$

or—

$$M = \frac{P}{6\,h}\,\{a\,(h^4-2\,k^4)+a_1\,h_1^4\} - \frac{P^2}{10\,h^2}\{\beta\,(h^5-2\,k^5)+\beta_1\,h_1^5\}$$

Here also results may be made more general by expressing the displacement of the neutral axis in terms of the depth of the beam.

Letting $h = m\,H$, and $h_1 = (2-m)\,H = m_1\,H$, and $k = (m-1)\,H$, the following equation for determining the position of the neutral axis is obtained—

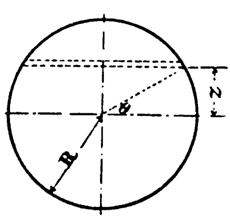
$$a\,\{m^3-2\,(m-1)^3\}-a_1\,m_1^3 = \frac{P}{2\,m}\,(\beta\,\{m^4-2\,(m-1)^4\}-\beta_1\,m_1^4)$$

and internal moment of resistance

$$= H^3\left[\frac{P}{6\,m}\left(a\,\{m^4-2\,(m-1)^4\}+a_1\,m_1^4\right)\right.$$
$$\left.-\frac{P^2}{10\,m^2}\left(\beta\,\{m^5-2\,(m-1)^5\}+\beta_1\,m_1^5\right)\right]$$

Case III.—Beam of circular section (*Fig. 5*). Total depth of section = 2 R.

Fig. 5.



The integrals to determine the position of the neutral axis are easily obtained, but the equation resulting from their integration is too complex to be of any use, while the expression for the moment of resistance of the beam is also very involved. A large proportion of the errors of the ordinary theory may be eliminated, however, by assuming that the stress-strain curve of compression is the same as that of tension, the neutral axis remaining central. It is evident that the strength of a beam thus

determined must be less than its real value, since the extra strength of the metal against compression at high intensities of stress is ignored.

The equation to the stress-strain curves, both of tension and compression, being $y = \alpha x - \beta x^2$, and the neutral axis, in consequence, being central:—

The moment of resistance of the beam will be—

$$\int_{-R}^{R} 2\, R \cos\theta \left(\alpha\, P\, \frac{z}{R} - \beta\, P^2 \frac{z^2}{R^2}\right) z\, dz$$

$$= \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 2\, R^3 \cos^2\theta \sin\theta\, (\alpha P \sin\theta - \beta\, P^2 \sin^2\theta)\, d\theta$$

$$= \left(\frac{\pi\, \alpha\, P}{4} - \frac{8\, \beta\, P^2}{15}\right) R^3$$

i.e., internal moment of resistance

$$= R^3 \left\{\frac{\pi\, \alpha\, P}{4} - \frac{8\, \beta\, P^2}{15}\right\} \quad \text{(Approximate method.)}$$

Application of Formulas:—For the quality of cast iron employed in the experiments the constants have been found to be:—

$$\alpha = \alpha_1 = 1{,}690$$
$$\beta = 24. \quad \beta_1 = 7$$

P = 35·2 thousandths of an inch at the assumed fracture-point of 29,750 lbs. per square inch, the vertex of the parabola; while the breaking-load, as ascertained by tension experiments, and as would be used in calculations under the ordinary theory, is 29,170 lbs. per square inch.

Case I.—Beam of rectangular section:—

The equation to determine the neutral axis has been found to be:—

$$\tfrac{1}{2}\,(\alpha\, m^2 - \alpha_1\, m_1{}^2) = \frac{P}{3\, m}\,(\beta\, m^3 - \beta_1\, m_1{}^3)$$

which gives the values

$$m = 0{\cdot}54, \; m_1 = 0{\cdot}46,$$

i.e., the neutral axis at fracture is displaced 4 per cent. of the total depth of the beam, towards the compression side.

The moment of resistance is given by

$$M = K\, H^2 \left\{\frac{P}{3\, m}\,(\alpha\, m^3 + \alpha_1\, m_1{}^3) - \frac{P^2}{4\, m^2}\,(\beta\, m^4 + \beta_1\, m_1{}^4)\right\}$$

or, $$M = 6860\ K\ H^2$$

i.e., internal moment of resistance = 6860 K H².

Y 2

Under the ordinary theory, the moment is the product of the maximum tensile strength and the modulus of the section,

i.e., $$29{,}170 \times \frac{K\,H^2}{6}, = 4{,}862\ K\,H^2.$$

The apparent (calculated) strength of the beam has therefore been increased by 41·1 per cent.

Case II.—Beam of square-on-angle section:—

The equation to determine the neutral axis is—

$$a\,\{m^3 - 2\,(m-1)^3\} - a_1\,m_1{}^3 = \frac{P}{2\,m}\Big(\beta\,\{m^4 - 2\,(m-1)^4\} - \beta_1\,m_1{}^4\Big)$$

whence are obtained

$$m = 1{\cdot}036,\ m_1\,(= 2 - m) = 0{\cdot}964$$

.*e.*, the neutral axis at fracture is displaced 3·6 per cent. of the beam, semi-diagonal, or 1·8 per cent. of the total depth of the section, towards the compression side.

The moment of resistance is given by—

$$M = H^3\left[\frac{P}{6\,m}\Big(a\,\{m^4 - 2\,(m-1)^4\} + a_1\,m_1{}^4\Big) - \frac{P^2}{10\,m^2}\Big(\beta\,\{m^5 - 2\,(m-1)^5\} + \beta_1\,m_1{}^5\Big)\right]$$

which on substitution becomes $M = 15{,}300\ H^3$.

i.e., internal moment of resistance $= 15{,}300\ H^3$.

Under the ordinary theory, the modulus of the section is $\frac{H^3}{3}$, and the internal moment $29{,}170\ \frac{H^3}{3}$ or $9{,}723\ H^3$. The apparent strength of the beam is therefore increased 57·3 per cent.

Case III.—Beam of circular section (approximation only, assuming that the neutral axis is central, and the compression- and tension-curves similar):—

The moment of resistance is given by—

$$M = \left\{\frac{\pi\,a\,P}{4} - \frac{8\,\beta\,P^2}{15}\right\} R^3$$

whence, taking $a = 1{,}690$, $\beta = 24$, and $P = 35{\cdot}2$,

Internal moment of resistance = 30,900 (approximate method).

Under the ordinary theory, the modulus of a circular section is $\frac{\pi}{4}\,R^3$, and the internal moment would be $29{,}170 \times \frac{\pi}{4}\,R^3$, or $22{,}910\ R^3$.

Thus by an approximate method, in which the extra strength of cast iron against compression has not been taken into account, the apparent strength of the beam has been raised 34·9 per cent.

If this approximate method, in which both stress-strain curves are regarded as being that of tension, be applied to beams of rectangular and square-on-angle sections, the amount of error in these cases due to ignoring the displacement of the neutral axis is at once obtained, and the correction that must be made in the foregoing calculation for the cylindrical beam may be estimated approximately.

By putting $a = a_1$ and $\beta = \beta_1$, which necessitated $m = m_1$ in the equations already obtained, the following approximate expressions for the moment of resistance are found:—

Beam of rectangular section—

$$\text{M (app.)} = \text{K H}^2 \left(\frac{a\,\text{P}}{6} - \frac{\beta\,\text{P}^2}{8}\right)$$

or, if $a = 1{,}690$, $\beta = 24$, and $\text{P} = 35 \cdot 2$,

$$\text{M (app.)} = 6{,}200\ \text{K H}^2$$

which is 9·6 per cent. less than the more correct value already obtained, namely, 6,860 K H^2.

Beam of square-on-angle section.

$$\text{M (app.)} = \left(\frac{\text{P}\,a}{3} - \frac{\text{P}^2\beta}{5}\right)\text{H}^3$$

or, inserting the values of a, β, and P,

$$\text{M (app.)} = 13{,}900\ \text{H}^3$$

i.e., 9·2 per cent. less than the more correct value.

Thus in these two cases the errors due to neglecting the difference between the stress-strain curves are respectively 9·6 per cent. and 9·2 per cent. As the distribution of area in a circle is intermediate between that of a square on its angle and that of a rectangle (referring to the horizontal diameter), it may be assumed that the error in the case of a cylindrical beam will lie between these two figures, and may be taken as 9·4 per cent.

With this assumption the corrected moment of resistance of the cylindrical beam will be 34,100 R^3 as against 30,900 R^3 obtained by the approximate method, and 22,910 R^3 given by the ordinary theory, while the total increase of strength above that given by the ordinary theory is 48·9 per cent. In future references to cylindrical beams, the highest value, 34,100 R^3, will be taken as the true internal moment of resistance.

TABLE III.—CAST-IRON BEAMS.

Relative strength according to calculations based on the ordinary theory, and on the more rigorous theory.

Type of Section of Beam.		Strength by Ordinary Theory.	Strength by Modified Theory.	Increase of Apparent Strength over Ordinary Theory
				Per Cent.
Rectangular . .		4,862 K H^2	6,860 K H^2	41·1
Square-on-angle .		9,723 H^3	15,300 H^3	57·3
Circular . . .		22,910 R^3	34,100 R^3	48·9

In *Fig. 6* is shown graphically the great increase that is found in the apparent strength of a rectangular beam, on taking into account the shape of the stress-strain curves. The diagram represents the cross-section of a rectangular beam, on which the equivalent-stress and equivalent-moment curves obtained by the ordinary theory are shown in the upper right-hand and lower left-hand quarters, and similar figures for the more rigorous theory are shown in the upper left-hand and lower right-hand quarters. The curves of equivalent stress given by the ordinary theory are obtained by drawing the diagonal of the rectangle, and the curves of equivalent moment are obtained by projection from the equivalent-stress curves, as shown by dotted lines. The sum of the areas enclosed by these two curves and the axes, multiplied by the height of the beam, gives at once the modulus of the section, and on multiplying this by the fracturing tension-stress, the apparent strength of the beam, according to the ordinary theory, is obtained. The equivalent-stress curves for the more rigorous theory are obtained by drawing the stress-strain curves of the metal, taking the vertical centre-line as axis of strain, and the neutral axis of the beam (here displaced 4 per cent. of the beam's depth) as axis of stress, and choosing scales so that the corner of the beam's section represents the tension fracture-point. The projections to obtain the equivalent-moment curves have been made, as shown by dotted lines, upon bases at a distance from the neutral axis equal to the semi-depth of the beam, so that the sum of the two resulting areas, multiplied by the beam's depth gives, as before, the modulus of the section; and this multiplied by the fracturing tension-stress gives the apparent strength of the beam based on the modified theory. Thus the areas of the equivalent-moment figures

(shaded), represent the comparative apparent strengths of the beam according to the ordinary and the modified theories, assuming the same fracturing stress under tension in each case; *i.e.*, having allowed in the ordinary theory for the lack of homogeneity of the metal.

Comparison of Theory with Results of Experiment.—As already mentioned, nine bars for bending-tests were cast simultaneously with the tension and compression specimens—three of each type of section. The bars were machined all over, a fair amount of metal being removed in order that these tests might conform with the others as closely as possible. Those of rectangular section were uniform throughout, while those of square-on-angle and circular sections had narrow bearing-strips cast on them to prevent local crushing. The tests were made in the usual manner, care being taken, however, that the load should be increased continuously right up to fracture-point, without being removed after once applied. The results of these experiments are given in Table IV., where the actual strength of each bar is compared both with that deduced by the ordinary theory, and with that determined by the more rigorous calculations described in the foregoing. The figures of this Table are satisfactory in so far as they tend to show that the faultiness of the ordinary beam-theory as applied to cast iron is largely due to the causes already pointed out, since with each type of beam the greater part of the discrepancy between theory

Fig. 6.

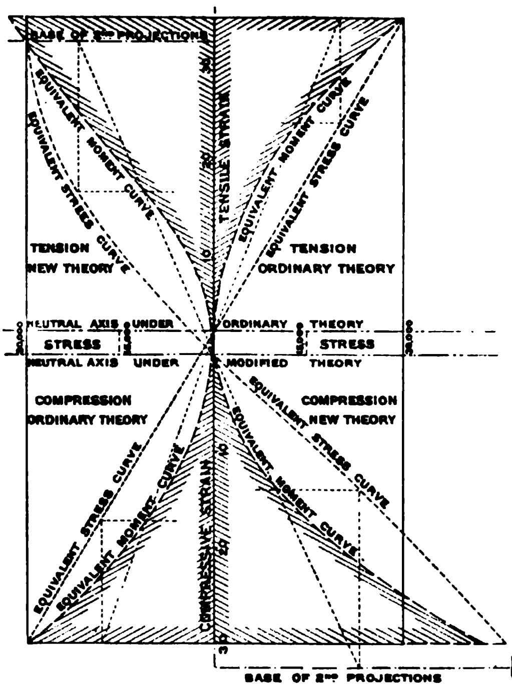
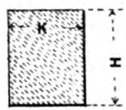
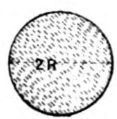


TABLE IV.—CAST-IRON BEAMS. COMPARISON OF EXPERIMENT WITH ORDINARY AND AMENDED THEORIES.

	Type of Section.	Dimensions.	Load on Centre at Fracture.	Span.	External Bending Moment.	By Ordinary Theory. Internal Bending Moment.	By Ordinary Theory. Ratio $\frac{\text{E. B. Mt.}}{\text{I. B. Mt.}}$	By Amended Theory. Internal Bending Moment.	By Amended Theory. Ratio $\frac{\text{E. B. Mt.}}{\text{I. B. Mt.}}$
		Inches.	Lbs.	Inches.	Lb.-Inches.	Lb.-Inches.		Lb.-Inches.	
1	Rectangular. 	H = 1·752. K = 0·860	4,450	20	22,250	12,830	173·4 to 100	18,100	122·9 to 100
2		H = 1·697. K = 0·880	4,315	20	21,530	12,350	174·3 „ „	17,430	123·5 „ „
3		H = 1·746. K = 0·882	4,645	20	23,230	13,070	177·5 „ „	18,440	126·0 „ „
Mean	..	..	..	..	..	..	175·1 „ „	..	124·1 „ „
4	Square-on-angle. 	B = 1·156. H = 0·8175	2,480	19·8	12,280	5,312	231·0 to 100	8,360	146·9 to 100
5		B = 1·250. H = 0·884	2,893	19·8	14,320	6,717	213·2 „ „	10,570	135·5 „ „
6		B = 1·231. H = 0·8705	2,821	19·8	13,960	6,414	217·7 „ „	10,090	138·3 „ „
Mean		..	..	..	..	..	220·6 „ „	..	140·2 „ „
7	Circular. 	R = 0·682	2,485	20	12,430	7,268	170·9 to 100	10,820	114·8 to 100
8		R = 0·663	2,205	20	11,030	6,676	165·1 „ „	9,940	110·9 „ „
9		R = 0·6575	2,250	20	11,250	6,512	172·8 „ „	9,694	116·4 „ „
Mean		..	..	..	..	..	169·6 „ „	..	114·0 „ „

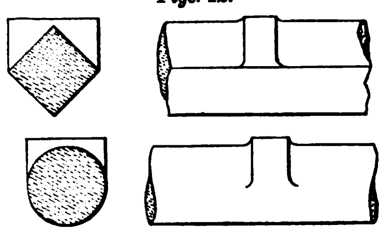
NOTE.—Formulas for internal bending moment (from Table III.)

Section.	Rectangular.	Square-on-Angle.	Circular.
Ordinary theory	$4{,}862\ K H^2$	$9{,}723\ H^3$	$22{,}910\ R^3$
Amended theory	$6{,}860\ K H^2$	$15{,}800\ H^3$	$34{,}100\ R^3$

and experiment has been eliminated. At the same time it seems very evident that there must be some factor of no small importance that has hitherto been overlooked; for although the tests in tension and compression were but few, and revealed unpleasantly large variations in the quality of the cast iron, still it is certain that any small errors there may be in the assumed form of the stress-strain curves, or in the fracturing tension-stress, would be quite insufficient to produce the discrepancy still remaining between the results of calculation and of actual test,—over 40 per cent. with one type of beam.

A small correction should have been made in the case of the beams of square-on-angle and circular sections, to allow for the effect of the central bearing-strip used to prevent local damage to the metal, *Figs.* 12. This of course strengthened the central section of the beam, and caused it to break slightly to one side, where the external bending-moment was rather less than that given in the Table. As the bearing strip was about ⅝ inch in width, and the span approximately 20 inches, the order of this correction must be about 3 per cent. Unfortunately the point was not observed at the time. Had the position of fracture been noted in each case, the actual bending-moment upon the ruptured section could have been ascertained; but as this was omitted it was deemed inadvisable to introduce into the figures of Table IV. what could be only an approximate correction.

Figs. 12.

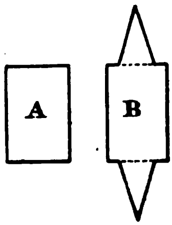


It may be noted here that the results obtained for beams of circular section are distinctly anomalous, their ascertained strength being considerably less than that which might have been expected from experiments of others, a divergence-factor of 1·9 to 2·0 between actual strength and that by the ordinary theory being what is usually found. The factors with the other two types of beam are quite normal.

The case of a beam of square-on-angle section, however, requires further consideration. The foregoing investigation gives, rigorously, upon the assumed basis, the internal bending-moment when the outermost tensile fibre is on the point of rupture. It does not follow, however, that at this point the whole

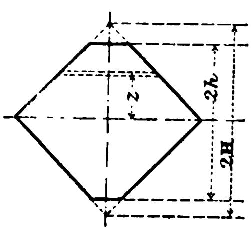
beam must collapse. It has been pointed out by Mr. E. C. de Segundo,[1] Assoc. M. Inst. C.E., that with a beam of rectangular section the modulus may be greatly lowered if additional metal is added in the shape of two thin fins, as shown in *Figs.* 7; and he interprets this as showing that the theory of beams is not applicable to the case of a beam of such a section as that shown at B (*Figs.* 7). But this interpretation is not altogether justifiable; the beam theory only denotes the load at which the outer fibre must rupture, and in some cases it cannot be said that therefore the second and all other fibres must also give way, for it is evidently possible for the fin to be fractured from top to bottom without injury to the rectangular portion of the beam. It is only necessary to imagine a web made deep and very thin indeed to see that this must happen.

Figs. 7.



The fact seems to have been overlooked that a beam of square-on-angle section is very analogous to the winged beam referred to by Segundo. The modulus of such a beam is given in text-books as $\frac{H^3}{3}$; but assuming the material to be strictly elastic, and the ordinary theory of beams to be perfectly correct, the load producing the apparent rupturing moment $\frac{F\,H^3}{3}$ will suffice to break the outermost fibre of the beam, but not the succeeding fibres. In other words, if metal be removed from the top and bottom corners of a square-on-angle beam, its modulus of resistance will be raised.

Fig. 8.



Assuming a material truly elastic and equally strong in tension and in compression, it is a simple matter to determine the amount of metal that must be removed from the top and bottom corners of a beam of square-on-angle section in order that, the section remaining symmetrical, the modulus may be a maximum :—

Let the beam, as shown in *Fig.* 8, have a depth $2\,h$, the diagonal of the full square being $2\,H$.

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[1] Minutes of Proceedings Inst. C.E., vol. xcviii. p. 313.

The modulus of the truncated section will be—

$$M_h = 4\int_0^h (H - z)\frac{z^2}{h}\,dz$$

$$= 4\left\{\frac{Hh^2}{3} - \frac{h^3}{4}\right\}.$$

For the maximum value of this expression—

$$\frac{d\,M_h}{d\,h} = 0,$$

i.e.

$$\frac{2\,H\,h}{3} - \frac{3\,h^2}{4} = 0,$$

whence—

$$h = 0 \text{ or } \frac{8}{9}H.$$

And clearly $h = \frac{8}{9}$ H is the value required; *i.e.*, one-ninth of the semi-depth must be removed from each of the two corners to give the maximum apparent modulus.

Substituting $h = \frac{8}{9}$ H in the foregoing equation—

$$M_{max} = \frac{256}{729}H^3.$$

The modulus of the full section (of depth 2 H) is $\frac{H^3}{3}$; *i.e.*, the removal of one-ninth of the semi-depth, top and bottom, increases the modulus in the ratio 243 to 256, or by 5·3 per cent.

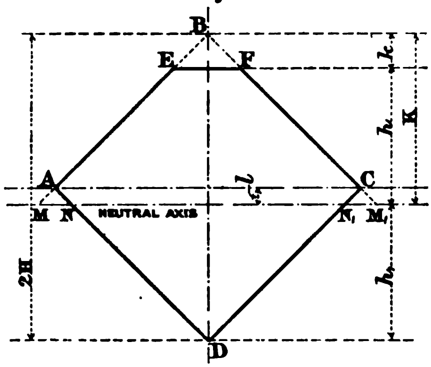
With cast iron there is no reason for removing metal from the compression corner, since the maximum compressive stresses at the time of the beam's rupture cannot nearly approach the ultimate crushing stress. If the compression corner is not removed the position of the neutral axis will be altered, and additional metal may with advantage be removed from the tension corner.

In determining the amount of metal that must be removed from the tension corner of a beam of square-on-angle section, in order that the modulus may be a maximum, two cases will be considered, (1) the material being truly elastic, and (2) only semi-elastic.

Case I.—Material truly elastic, and with equal coefficients of extension and compression, but with a much greater ultimate strength against crushing than against tension (*Fig. 9*). Let

the diagonal of the original square be 2 H, of which a depth k has been removed from the upper (tension) corner. The neutral axis will no longer be central, but will be displaced downwards by an amount l. Let its distance from the outer tension and compression fibres be respectively h and h_1, and its distance from the upper corner of the square, if completed, K.

Fig. 9.



Then $h + h_1 + k = 2\,H$, $h = H + l - k$, $h_1 = H - l$, and $K = H + l$.

The position of the neutral axis is determined by the fact that the sum of all the longitudinal forces must be *nil.* Considering the tension area as the difference between the figure M E F M_1, and the two triangles M A N, N_1 C M_1,

The total tensile force over the area N A E F C N_1 is—

$$\int_0^h 2\,S\,\frac{z}{h}\,(K - z)\,d\,z - \int_0^l 4\,S\,\frac{z}{h}\,(l - z)\,d\,z$$

$$= 2\,S\left(\frac{K\,h}{2} - \frac{h^2}{3} - \frac{l^3}{3\,h}\right),$$

where S is the stress in the outermost tension-fibre.

And the sum of all the compressive forces over the triangle N_1 D N is—

$$\int_0^{h_1} 2\,S\,\frac{z}{h}\,(h_1 - z)\,d\,z$$

$$= \frac{S\,h_1^{\,3}}{3\,h}.$$

For equilibrium these two must be equal,

whence $$3\,K\,h^2 - 2\,h^3 - 2\,l^3 = h_1^{\,3} \quad . \quad . \quad . \quad . \quad (1)$$

which determines the position of the neutral axis with any given amount of truncation.

Again, the moment of all the tensile forces is—

$$\int_0^h 2\,S\,\frac{z}{h}\,(K - z)\,z\,d\,z - \int_0^l 4\,S\,\frac{z}{h}\,(l - z)\,z\,d\,z$$

$$= 2\,S\left(\frac{K\,h^2}{3} - \frac{h^3}{4} - \frac{l^4}{6\,h}\right),$$

and of all the compressive forces,

$$\int_{o}^{h_1} 2\,S\,\frac{z}{h}\,(h_1 - z)\,z\,d\,z$$
$$= S\,\frac{h_1^4}{6\,h}.$$

The moment of the whole section is therefore—

$$\frac{S}{6\,h}\,(4\,K\,h^3 - 3\,h^4 - 2\,l^4 + h_1^4),$$

or the modulus of the section,

$$M_k = \frac{1}{6\,h}\,(4\,K\,h^3 - 3\,h^4 - 2\,l^4 + h_1^4) \quad . \quad . \quad (2)$$

which can be determined when the position of the neutral axis has been ascertained.

For actual numerical determination of the position of the neutral axis, and the modulus of the section, it is more convenient to express these two quantities in terms of H, the semi-diagonal of the square.

Let $k = n\,H$, and $l = m\,H$, so that 100 n and 100 m are respectively the truncation of the tension-corner, and the consequent shift of the neutral axis from the mid-position, expressed as percentages of the semi-diagonal.

Then $K = H\,(1 + m)$, $h = H\,(1 + m - n)$ and $h_1 = H\,(1 - m)$; whence the expression determining the neutral axis becomes—

$$3\,(1 + m)\,(1 + m - n)^2 - 2\,(1 + m - n)^3 - 2\,m^3 = (1 - m)^3$$

and the modulus of the section becomes—

$$\frac{H^3}{6\,(1+m-n)}\,\{4\,(1-m)\,(1+m-n)^3 - 3\,(1+m-n)^4 - 2\,m^4 + (1-m)^4\}$$

As the modulus of the original square (M_o) is $\frac{H^3}{3}$ it follows that—

$$\frac{M_n}{M_o} = \frac{1}{2\,(1 + m - n)}\,\{4\,(1 + m)\,(1 + m - n)^3$$
$$- 3\,(1 + m - n)^4 - 2\,m^4 + (1 - m)^4\}$$

M_n being the modulus with 100 n per cent. of the semi-diagonal removed.

These expressions do not readily lend themselves to an exact determination of the maximum value of M_n; but in Table V. are given the values of m and of M_n, expressed respectively as percentages of the semi-diagonal, and of the modulus of the original square, for different values of n, *i.e.*, with different percentages

of the semi-depth removed; and from this it will be seen that the maximum modulus is reached when (roughly) one-quarter of the semi-depth (or one-eighth of the total depth) of the beam has been removed, and that this modulus is over 11 per cent. greater than that of the full square-on-angle section. Further, it is worthy of note that, provided the material is 50 per cent. stronger in compression than in tension, a saw-cut might be

TABLE V.—BEAM ASSUMED TO BE OF A PERFECTLY ELASTIC MATERIAL, CONSIDERABLY STRONGER IN COMPRESSION THAN IN TENSION.

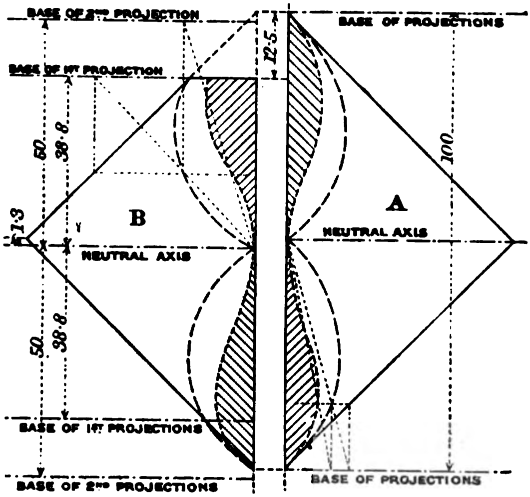
Depth of Metal Removed from Tension-Corner. Percentage of Semi-Diagonal, *i.e.*, 100 *n*.	Shift of Neutral Axis from its Mid-Position. Percentage of Semi-Diagonal, *i.e.*, 100 *m*.	Modulus of Section. Percentage of Modulus of Original Square, *i.e.*, $100 \frac{M_n}{M_o}$.	Ratio of Maximum. Compressive Stress to Maximum Tensile Stress.
Per Cent.	Per Cent.	Per Cent.	Per Cent.
0	0	100	100
5·0	0·12	104·37	105·0
10·0	0·47	107·63	110·0
15·0	1·02	109·81	115·1
20·0	1·77	111·04	120·1
21·0	1·939	111·15	121·3
22·0	2·116	111·25	122·2
23·0	2·300	111·31	123·2
24·0	2·491	111·34 –	124·3
24·5	2·589	111·34 +	124·8
25·0	2·688	111·34 –	125·3
26·0	2·892	111·30	126·3
28·0	3·32	111·13	128·4
30·0	3·77	110·84	130·4
35·0	5·00	109·63	135·7
40·0	6·38	107·72	141·0
50·0	9·52	102·25	152·0
54·0	10·92	99·52	156·0

made in a beam of square-on-angle section, extending from the tension-corner over half-way to the horizontal diagonal, without the modulus falling below that usually quoted for the full square.

In *Fig. 10* is shown, graphically, a comparison between the modulus of a beam of square-on-angle section and the modulus of the same beam after 25 per cent. of its semi-depth has been removed from the tension-corner. Following upon the method of Professor

Hummel, double projections are made, obtaining first the figures of equivalent stress, and then the figures of equivalent moment. As the second projections are in each case made with reference to a line at a distance from the neutral axis equal to the semi-diagonal of the square, the moduli of the two sections, full square and truncated square, are directly proportional to the areas of the figures of equivalent moment (shaded).

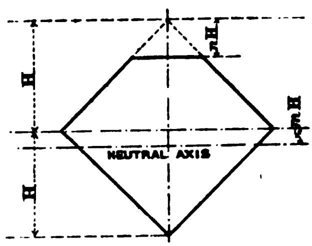
Fig. 10.



In the case of cast iron, where the material is not truly elastic, the problem is capable of solution if the stress-strain curves are assumed to be parabolic, in the manner indicated below.

Case II.—Material semi-elastic, having parabolic stress-strain curves, and much stronger against compression than against tension (*Fig. 11*):—

Fig. 11.



Let H be the semi-diagonal of the square, nH the vertical depth of metal removed from the tension-corner, and mH the distance of the neutral axis from the horizontal diagonal of the square; then if as before, $y = \alpha x - \beta x^2$ and $y = \alpha_1 x - \beta_1 x^2$ represent the stress-strain curves for tension and compression respectively, and P be the limiting value of tensile strain, the following results are obtained.

The position of the neutral axis—*i.e.*, the value of m—is determined by the equation—

$$
\begin{aligned}
6\alpha(1+m-n)^3(1+m) &- 4\alpha(1+m-n)^4 \\
&- 4\alpha m^3(1+m-n) - 2\alpha_1(1-m)^3(1+m-n) \\
&= 4\beta P(1+m-n)^3(1+m) - 3\beta P(1+m-n)^4 \\
&\qquad - 2\beta P m^4 - \beta_1 P(1-m)^4
\end{aligned}
$$

And the moment of resistance of the section has the value—

$$
\begin{aligned}
M_n = H^3 \Big\{ & \frac{2\,a\,P}{3}(1+m)(1+m-n)^2 - \frac{a\,P}{2}(1+m-n)^3 \\
& - \frac{a\,P}{3}\,\frac{m^4}{1+m-n} + \frac{a_1\,P}{6}\,\frac{(1-m)^4}{1+m-n} \\
& - \frac{\beta\,P^2}{2}(1+m)(1+m-n)^2 + \frac{2\,\beta\,P^2}{5}(1+m-n)^3 \\
& + \frac{\beta\,P^2}{5}\,\frac{m^5}{(1+m-n)^2} - \frac{\beta_1\,P^2}{10}\,\frac{(1-m)^5}{(1+m-n)^2} \Big\}
\end{aligned}
$$

By giving specific values to a, a_1, β, β_1, and P—constants dependent on the quality of the material of the beam—m and M_n are determined for any particular value of n. It is evident from the formulas that, provided the material is uniform in quality, the strengths of symmetrical beams are proportional to the cubes of their linear dimensions, and that the proportionate effect of a given percentage of truncation is the same with all sizes of beam.

The values of m and of M_n corresponding to increasing values of n, for a beam of cast iron, are given in Table VI., the same assumptions being made as before, viz., that the curves of tension and compression are strictly parabolic, and that the fracture under tensile strain takes place at the point represented by the vertex of the stress-strain parabola. The constants for the cast iron used are those deduced from Tables I. and II., viz.:—

$$a = a_1 = 1690$$
$$\beta = 24, \quad \beta_1 = 7, \quad P = 35 \cdot 2,$$

the units employed being pounds per square inch for stress and thousandths of an inch upon 10 inches for strain.

It will be seen from the Table that the maximum apparent moment of resistance is reached when 19½ per cent. of the semi-diagonal has been removed, and that the modulus is then 6·19 per cent. greater than that of the original beam.

It would be interesting to test the breaking strength of beams of truncated square-on-angle section, with a view to ascertaining whether the theory that a considerable amount of metal may be removed from the tension corner without impairing the beam's strength is borne out by experiment.

There is, however, one additional point which is worthy of attention. In the ordinary beam-theory no account is taken of any stresses other than those of bending. It should therefore only be applied when the local effects of all external forces acting on the beam are so small as to be negligible. This would doubtless be the case with a beam loaded distributively over a

TABLE VI.—BEAM ASSUMED TO BE CONSIDERABLY STRONGER IN COMPRESSION THAN IN TENSION, AND TO HAVE PARABOLIC STRESS-STRAIN CURVES.

Depth of Metal Removed from Tension-Corner. Percentage of Semi-Diagonal, *i.e.*, 100 n.	Distance of the Neutral Axis from Mid-Position. Percentage of Semi-Diagonal, *i.e.*, 100 m.	Apparent Moment of Resistance of Section in Terms of H^3, *i.e.*, M_n.	Percentage Ratio of Modulus of Section to Modulus of the Original Square, *i.e.*, $100 \frac{M_n}{M_0}$.
Per Cent.	Per Cent.		Per Cent.
0	3·62	15,308 H^3	100·00
5·0	3·93	15,745 H^3	102·86
10·0	4·40	16,043 H^3	104·8
15·0	5·04	16,209 H^3	105·89
17·0	5·34	16,241 H^3	106·09
18·0	5·49	16,250 H^3	106·15
19·0	5·65	16,254 H^3	106·18
19·5	5·74	16,255 H^3	106·19
20·0	5·82	16,254 H^3	106·18
21·0	6·00	16,250 H^3	106·15
22·0	6·18	16,241 H^3	106·09
25·0	6·75	16,188 H^3	105·75
30·0	7·79	16,025 H^3	104·68
35·0	8·97	15,767 H^3	103·00
40·0	10·32	15,427 H^3	100·78
41·5	10·74	15,298 H^3	99·93

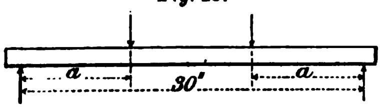
large part of its length; but when the load is applied along a transverse line by a slightly rounded bearing-edge, as in an ordinary test, it is certainly not safe, *a priori*, to neglect local stresses. It has been shown by Mr. C. A. Carus-Wilson,[1] M.A., Assoc. M. Inst. C.E., that in such a case as this, especially if the beam has a small ratio of length to depth, the local strains in the neighbourhood of the bearing-edge must considerably modify the distribution of the longitudinal strains in the beam. It would be useful, therefore, if experiments were made upon distributively-loaded beams in order to avoid these local effects. A test in which the load is uniformly distributed is difficult to arrange, but by adopting a method followed by Mr. E. C. de Segundo,[2] and applying the load at two points at equal distances from the ends, the maximum bending-moment is uniform over a considerable length of the beam—a length, moreover, free from shearing stress—the central portion of which is well removed from the point of application of the load. Comparative tests of strength under single and double loading, made by Segundo, were largely vitiated by faulty castings; and in order to obtain further evidence as to the effects of

[1] Proceedings of the Physical Society of London, 1891.
[2] Minutes of Proceedings Inst. C.E., vol. xcviii. p. 308.

local stresses, the following experiments were made. Nine bars of cast iron were obtained, all cast from the same ladle, and were machined to an approximately uniform section of $1\frac{3}{4}$ inch by $\frac{7}{8}$ inch, about $\frac{1}{8}$ inch thickness of metal being removed all over. Six of these bars were 2 feet 8 inches in length, and three bars were 1 foot 10 inches in length. The latter were broken by single loading, on a span of 18·8 inches, and two of the longer bars were broken similarly on a span of 30 inches. The remaining four bars were also tested upon a 30-inch span, but in double loading, the loads being applied at two points about 11 inches apart. The amount of the leverage, *a* (*Fig. 13*), was in each case measured from the trace of the bearing-edges left on the broken bars.

The results of these tests are given in Table VII., and show that beams broken under single loading on a short span are about 4 per cent. stronger than those similarly broken on the longer span, and 8 per cent. stronger than those tested under double loading; and although it was found that the doubly-loaded beams broke indiscriminately either at the centre of the span or under the bearing-edges, thus seeming to indicate that between these bearing-points the strength to resist bending is uniform, and does not diminish towards the centre as might be expected if local stresses impart strength, yet considering that the comparative intensity of transverse stress is least in the doubly-loaded beam, and greatest in that singly loaded on the short span, there seems to be reason for believing that severe local crushing stresses may add somewhat to the strength of a beam to resist fracture by bending.

Fig. 13.



The doubly-loaded beam being, for a considerable portion of its length, under uniform bending-moment, any point of special weakness may cause fracture to take place early; so that a slightly lower breaking-strength may be expected than is obtained with single loading, where fracture must occur in the vicinity of one point. But 8 per cent. is much too large a variation to be attributed to this cause, especially as each bar revealed a thoroughly good fractured surface, with no trace of any flaw. A correction of about 2 per cent. having been adopted as representing the difference between the average and the minimum tensile strength in a tension test-piece, a similar allowance might be made in bending-tests; but it is doubtful if this would not be excessive,

TABLE VII.—COMPARATIVE TESTS OF CAST-IRON BEAMS (RECTANGULAR SECTION) IN SINGLE AND DOUBLE LOADING.

Details of Loading.				Dimensions of Bars.			External Bending Moment. E. B. M.	Strength Factor $\frac{E. B. M}{K H^2}$.		Ratio of Strength Factor to that in Double Loading.	Remarks.
Type.	Span.	Leverage.	Breaking Load.	Depth H.	Width K.	K H².		Particular.	Mean.		
	Inches.	Inches.	Lbs.	Inches.	Inches.		Lb.-Inches.				
Single.	18·8	9·4	4,590	1·754	0·877	2·698	21,570	7,995	8,066	108·2 to 100	Broke 0·15 inch (mean) from bearing edge.
			4,600	1·753	0·876	2·692	21,620	8,032			Broke 0·1 inch (mean) from bearing edge.
			4,690	1·754	0·877	2·698	22,050	8,170			Broke 0·2 inch (mean) from bearing edge.
	30	15	2,780	1·749	0·873	2·670	20,840	7,810	7,740	103·9 to 100	Broke 0·35 inch (mean) from bearing edge.
			2,730	1·748	0·874	2·670	20,470	7,670			Broke 0·15 inch (mean) from bearing edge.
Double. (*Fig. 13.*)	30	9·51	4,350	1·748	0·876	2·677	20,680	7,730	7,450		Broke in two places. Beneath one bearing edge, and 1 inch inside the other.
		9·41	4,270	1·749	0·874	2·673	20,090	7,516			Broke in one place; 3¼ inches inside bearing edge, *i.e.*, 2¼ inches from centre of beam.
		9·41	4,190	1·752	0·875	2·686	19,710	7,340			Broke in two places; 1 inch inside one bearing edge, and ⅓ inch outside the other.
		9·41	4,110	1·750	0·876	2·682	19,340	7,210			Broke in one place; 4½ inches inside bearing edge, *i.e.*, 1 inch from centre of beam.

since in the former case any weak spot in the metal will make its influence felt, no matter where it may be situated, while in a beam, on the other hand, a flaw must be close to the tension surface to have the maximum effect.

A comparison of the results of the Author's tests of beams under double loading with those carried out by Segundo would seem to indicate that there is considerable scope for further and more exhaustive investigation in this field.

Various equations have from time to time been deduced, to represent the stress-strain curves of cast iron, and the following is a summary of such of these as the Author has been able to find.

Eaton Hodgkinson[1] gives a parabolic formula, $y = \alpha x - \beta x^2$ (y representing stress and x strain) as representing the tension-curve, and one of similar form for that of compression, these being the equations which the Author has adopted. He also gives the formula $y = \alpha x - \beta x^2 + \gamma x^3 - \delta x^4$ as being more in accordance with his curves, but the last two coefficients are very arbitrary.

Homersham Cox[2] gives $y = \alpha x - \beta x^2 + \gamma x^3$ as representing Hodgkinson's curves much more closely than the simpler parabolic equation, and also an alternative form, $y = \dfrac{\alpha}{\dfrac{1}{x} + \beta}$, as agreeing with the curve to a considerable degree of approximation.

Professor Unwin[3] gives an inverse form, $x = \alpha y + \gamma y^3$, as being more exact both in the case of Hodgkinson's experiments and in some of his own.

Mr. E. C. de Segundo[4] finds the inverse parabola, $x = \alpha y + \beta y^2$ agree very well with tension-experiments, and failed to detect any diminution in the modulus of elasticity in compression.

The following investigations of the beam problem may also be mentioned :—

Hodgkinson[5] gives an elaborate investigation of the case of a beam of double-tee section, taking formulas of the general type $y = \alpha x - \beta x^n$ as representing tension and compression curves, and obtains very complex results. In the "Report of the Royal Commission on the Application of Iron to Railway and other

[1] "Report of the Royal Commission on the Application of Iron to Railway and Other Structures," 1849.

[2] Transactions of Cambridge Philosophical Society, vol. ix. pt. II., 1856, p. 177.

[3] "Testing of Materials of Construction" (Unwin), p. 256.

[4] Minutes of Proceedings Inst. C.E., vol. xcviii., 1888–89, p. 311.

[5] "Strength of Cast Iron," Tredgold and Hodgkinson.

Structures" he indicates how his parabolic equations may be applied to these expressions, but proceeds no farther than this.

Homersham Cox, in the Paper already referred to, applies his tension curve, $y = \frac{a}{\frac{1}{x} + \beta}$, to the theoretical investigation of the strength of a rectangular beam, endeavouring to work back from the experimental strength of such a beam, and to deduce the constants of a similar formula for compression, but without satisfactory result.

Professor Barlow [1] has applied general parabolic formulas to the case of a rectangular beam, but without substituting arithmetical values for his coefficients.

Professor Unwin [2] has worked out a case arithmetically, and, using modifications of Hodgkinson's parabolic equations, has compared the strength of a rectangular beam as calculated rigorously with that given by the ordinary theory, obtaining a ratio in favour of the former of 1·2 to 1—an increase which would have been found considerably higher but for an error introduced by the modifications already referred to. He contrasts this ratio with that of experimental to calculated strength, 1·74 to 1, as found by Messrs. Segundo and Robinson, but considers that the whole of this extra strength might be accounted for by the probability that the part of a tensile specimen at which fracture actually takes place will have undergone considerably greater strain before rupture than the remaining portion of the bar. He seems, however, to have subsequently modified his views somewhat, and to regard a mutual action between adjacent fibres as having some effect in raising the fracture-load of a beam.[3]

The experiments on which the foregoing Paper is based, were carried out by the Author in June, 1899 and March, 1901, at University College, London, under Professor T. Hudson Beare, B.Sc., M. Inst. C.E., to whom the Author is much indebted for assistance. The test-bars were specially cast for the purposes of the experiments by Messrs. G. Wailes & Company, of Euston Road.

The Paper is accompanied by drawings, from which the Figures in the text have been prepared.

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[1] "Strength of Materials," W. H. Barlow, 1867.

[2] *The Engineer*, 29 October, 1886.

[3] "Testing of Materials of Construction" (Unwin), p. 36.

OBITUARY.

SIR ANDREW CLARKE,[1] G.C.M.G., C.B., C.I.E., Lieutenant-General R.E. retired, died at his residence, 31 Portland Place, on the 29th March, 1902, after a long period of physical weakness and ill-health, which did not, however, prevent his discharging his important and manifold duties as Agent-General for the Colony of Victoria to the last. He died, as he wished to die, in harness, a strenuous worker to the end, and few of his contemporaries could show such a record of public service, spread over a period of nearly 60 years. As he was proud of recalling, he was the last survivor of the framers of the first Constitution of Victoria in 1855, and he lived to see the foundation of the Australian Commonwealth and to entertain the hope that he might be chosen as its first Imperial Commissioner in the capital of the Empire.

Born on the 27th July, 1824, at Southsea, Andrew Clarke was the son of Colonel Andrew Clarke, R.E., of Belmont, county Donegal, the first Governor of Western Australia. He had thus an inherited interest in the great island-continent with which so much of his career was connected. Educated at the King's School, Canterbury, and at the Royal Military Academy, Woolwich, he obtained a commission as second lieutenant in the Royal Engineers in 1844, and served for a short time in Ireland during the famine. He then received an appointment on his father's staff at Perth, but on his way out was induced to remain with Sir William Denison, Governor of Van Diemen's Land, or Tasmania, first as A.D.C., and afterwards as private secretary. His career thus began in Tasmania, and it is curious to note that he acted on several occasions as Agent-General of that colony. In 1848 he proceeded to New Zealand to take part in the Maori war, and for some years he served on the staff of Sir George Grey. An appointment as Surveyor-General attracted him to Victoria, where he found greater scope for his abilities; and in addition to his professional duties he took a prominent part in framing the Constitution of Victoria, a work of which he was especially proud because it was adopted by the home Government without a single alteration. When it came

[1] This Notice is reprinted, with some modifications, from *The Times* of the 31st March, 1902.

into force he was returned as member for Melbourne in the Legislative Assembly, and he held the office of Minister of Public Lands in the first responsible Administration of Victoria. After two years in office this Ministry resigned, in 1857, and Captain Clarke, declining an invitation to form an administration of his own, returned to England with twelve years' colonial experience, which in those days was extremely rare. In 1863 he was sent on a special mission to the West Coast of Africa in connection with some of the earlier troubles in Ashanti, but beyond a narrow escape from the only attack of fever he ever experienced in tropical climates, there was nothing important connected with this mission, which concluded the first part of his colonial career.

In 1864 he was appointed Director of Works for the Navy, a post he held for nine years. In that period the naval arsenals at Chatham, Portsmouth and Plymouth were so altered, improved and strengthened as to form practically new works. Similar fortified bases were constructed at Malta, Cork and Bermuda, where the floating dock was one of the engineering wonders of the day. His further suggestions with regard to Colombo, Singapore and other Imperial defences were not put into effect until he held the post of Inspector-General of Fortifications, nine years later. In 1873 he was appointed Governor of the Straits Settlements, where he did admirable work. He carefully studied the policy of Sir Stamford Raffles, the founder of Singapore, and he set himself the task of completing it by bringing the Malay States under the protection of Great Britain. In 1874 he proceeded to Perak, and by a succession of firm and well-conceived measures induced the Malay chiefs to sign the treaty of Pangkor, which bound them to accept British Residents. At the same time he induced the Chinese miners, whose faction fights had caused much trouble, to disarm. The results of these measures were that in the following twenty years the population more than trebled, the land revenue increased six hundred times, the imports and exports forty times, and the total revenue more than twentyfold. For beneficial administrative work unostentatiously performed there has never, perhaps, been a more striking example than was given by Sir Andrew Clarke in the Straits Settlements in 1874–75.

After nearly two years' pro-Consulship at Singapore, Sir Andrew returned to departmental work, this time in the large field of India, where for more than five years he was Minister of Public Works. His two most remarkable achievements in that capacity were perhaps the reduction of railway rates, which first enabled the Punjab to export its wheat, and the provision of cantonments

with a supply of pure water, at an outlay of three millions sterling, as the first step towards battling with typhoid. On his return to England, in 1881, he was in rather an anomalous position. He had held high offices, but his military rank was only that of Lieutenant-Colonel in the corps of Royal Engineers, and of full Colonel in the Army. No colonial posts were available, and he expressed a desire to return to professional duty. He was accordingly appointed Commandant at Chatham. From Chatham he passed, in 1882, to Pall Mall, as Inspector-General of Fortifications, a post which he held for four years. In a memorandum, dated June, 1886, he surveyed the work of that period, which included Imperial defences at all the principal naval stations, and home defences in the Tyne and Clyde. This part of his work may be considered the complement of that accomplished as Director of Naval Works nine years earlier. The organization of the Royal Engineers for submarine mine defences, the training of Engineer officers in the workshops of Elswick, and a number of minor technical matters constituted the record of his official work in this responsible position, the last he held in the service of the State.

Having closed his official career in 1886, when he attained the rank of Lieutenant-General, Sir Andrew Clarke sought Parliamentary honours, contesting Chatham in that year, and again in 1893, as a supporter of Mr. Gladstone. He was unsuccessful on both occasions. He possessed in a rare degree those qualities of coolness and courage which are demanded from rulers over dependencies, where a cloud no bigger than a man's hand may in an hour become a hurricane threatening destruction. His work at Singapore placed him in the front rank of British pro-consuls. Both as a technical and as a strategical engineer he did remarkable work. In his old age the Colony with which he had been associated in early manhood offered him the post of its Agent-General in the capital of the Empire. He was at all times an energetic representative of its interests, and a wise counsellor.

Early in 1902 Sir Andrew Clarke was gazetted Commandant of his old corps, the Royal Engineers, which restored him to the Active List. It will also be recollected that he presented the address of welcome from the colonial representatives in London to the Prince and Princess of Wales on their return from their Imperial tour. Sir Andrew was a leading Freemason and was Grand Master of Victoria from 1853 to 1858. He was made a K.C.M.G. in 1873, a C.I.E. in 1877, and a G.C.M.G. in 1885. He married one of the two daughters of Mr. Charles McKillop, of

Bath, by whom he leaves an only daughter. Lady Clarke died seven years ago.

Sir Andrew Clarke was elected an Associate of the Institution on the 4th April, 1865, and an Honorary Member on the 1st December, 1896, on the ground that during his long and distinguished career as an officer of the corps of Royal Engineers he had advanced the art of military engineering. In 1880 he presented a brief "Note on the Kandahar Railway."[1]

RICHARD DANSEY BAYLEY, born on the 12th December, 1833, obtained his early engineering experience on the East Indian Railway, on the construction of which he was engaged from 1857 to 1862. In 1865 he returned to England, where he was employed for two years as Agent to Messrs. Kelk and Lucas on the contract for extensions and improvements of the Great Eastern Railway at Harwich. In 1867 he was appointed to the Indian Public Works Department as an Executive Engineer in the Irrigation Branch, and in that capacity he was subsequently employed on the Upper Sutlej Canal, the Bari Doab Canal, and the Indus Canals in the Punjab. In 1883 and 1884 he held charge of the Derajat Circle as Superintending Engineer, and in 1885 of the Western Jumna Canal Circle. Three years later he resigned his connection with the Indian Public Works Department and returned finally to England, where he lived in retirement.

Mr. Bayley died at 31 Sion Hill, Bath, on the 19th January, 1902, in his sixty-ninth year. He was elected a Member of the Institution on the 1st May, 1888.

FREDERICK BEESLEY, born on the 4th April, 1836, commenced his professional career as an Assistant Engineer to the Metropolitan Commissioners of Sewers, having charge of the sewers in St. George's, Hanover Square, District. He also devoted much time to the study of architecture, and when only 20 years of age was awarded the first premium for his design for the schools at Hornchurch, Essex, which work he eventually carried out.

In 1860 he entered into partnership with the late Mr. Edward Gotto, an association which lasted for thirty years. Among some

[1] Minutes of Proceedings Inst. C.E., vol. lxi. p. 273.

of the works carried out by the firm of Gotto and Beesley were the drainage of Rio de Janeiro, Seaford, Trowbridge, Evesham, Huyton and Roby, Redditch, Romford, Chatham, Horsham, Tiverton, Brentford and Cheshunt; and the drainage and water-supply of Campos (Brazil), Oswestry, East Cowes, Leominster, Cinderford, Aberdovey, Herne Bay and Alton.

On the expiration of this partnership in 1890, Mr. Frederick Beesley continued to practise alone until 1897, when his son, Mr. Walter Beesley, became his partner. The principal works designed and carried out by Messrs. Fredk. Beesley and Son were the sewerage and sewage disposal of Southwold, Porthcawl, Frinton-on-Sea, Pembroke, Pembroke Dock, Leatherhead, Ashtead, Ewell, Cobham, Holmfirth, Newmarket, Worcester, Walton-on-the-Naze, Rodbourne-Cheney, Burry Port, Hayes, Stratton, Whitland, Neyland, Chertsey and Colyton, and the water-supplies of Haverfordwest, Blandford, Salcombe. Llanidloes, Pembroke Dock and Burry Port.

In 1899 Messrs. Fredk. Beesley and Son entered into partnership with Mr. H. Bertram Nichols, of Birmingham, when the style of the firm became Beesley, Son and Nichols. The works executed by this firm and in progress comprise the sewerage and sewage disposal of Brownhills, Foleshill, Cowbridge, Morecambe, Manaos (Brazil), Baildon, St. Albans, Emsworth, Sutton-in-Ashfield, Saffron-Walden, Tredegar, Huntingdon, Windermere, Truro, Walmer, Kendal, Devizes, Saxmundham, Bury St. Edmunds, and the sewerage of the Western Valleys of Monmouthshire; besides the water-supply of Bedworth, Braunton, Newtown, Honiton, Woodcote, Seaton, Kempston, Sturminster-Newton and Lynton.

Mr. Frederick Beesley retired from the firm at the end of 1900, but retained his appointment as Consulting Engineer to the Rio de Janeiro City Improvements Company. That post he held until his death, which occurred at his residence at Ealing on the 5th February, 1902, at the age of sixty-five.

He was elected a Member of the Institution on the 1st April, 1884.

PHILIP HENRY BROWN was born in London on the 2nd August, 1846, and was educated by his father, the Rev. George Brown, of Brighton, and subsequently at King's College, London. After serving a pupilage to the late Mr. P. Prichard Baly, he was appointed an Assistant Engineer on the Bombay-Baroda Railway in 1867. In the following year he entered the service of the Indian Public Works Department as an Assistant Engineer in the Irriga-

tion Branch. In 1872 he received the thanks of the Government for his work at the Sanouta Falls on the Ganges Canal, and five years later he volunteered for service in connection with the Madras Famine works.

Mr. Brown retired from the Indian Public Works Department in 1879, and in the following year he was appointed Local Fund Engineer at Coconada, and in 1884 District Engineer of the Godaveri Circle. These posts he held until his death, which took place on the 17th April, 1901.

Mr. Brown was elected an Associate Member of the Institution on the 6th April, 1880, and was transferred to the class of Members on the 26th March, 1895.

GEORGE COOPER, born in Preston on the 22nd May, 1836, was the third son of the late Mr. Edward Miles Cooper, a Manchester merchant and cotton spinner. After being educated at Rossall School he served a pupilage of four years, first with Messrs. Daniel Adamson and Company of Newton Moor Ironworks, and subsequently with Messrs. Benjamin Hick and Son of the Soho Ironworks, Bolton-le-Moors. For nine months in 1857–58 he took charge of a cotton mill in Portwood, Stockport, after which he returned to Messrs. Hick and Son, with whom he remained for over three years. In March, 1861, he entered the service of Mr. Edmund Sharpe of the Phœnix Foundry, Lancaster, as draughtsman, and, on the manager retiring a few months later, remained in charge of the technical work of the establishment until June, 1862, when, in view of the general depression of trade throughout Lancashire, due to the war in the United States, he resigned his post and emigrated to Buenos Aires. There he obtained employment as second engineer on board one of the river steamers plying between Buenos Aires and Monte Video. From March to June, 1863, he was engaged as draughtsman with the late Mr. John Coghlan, and for the remainder of that year he acted as Clerk to H.B.M. Consul at Buenos Aires.

In January, 1864, Mr. Cooper was appointed an Assistant Engineer, under Mr. Alfred Rumball, on the construction of the Buenos Aires Great Southern Railway, from Buenos Aires to Chascomus. On the completion of that work in December, 1865, he entered the service of the Company as Locomotive Superintendent, and took charge, in addition to the Locomotive Department, of the general stores and the stations at North and South Barracas.

In 1867, during the absence of the General Manager, Mr. Edward Banfield, Mr. Cooper took charge of the railway for nine months as Acting General Manager. At the end of September, 1868, he retired from the service of the Great Southern Company to take charge, as Constructing Engineer and General Manager, of the Central Argentine Railway for the contractors, Messrs. Brassey, Wythes and Wheelwright, with whom he remained until the line had been completed to Cordoba, opened throughout to public traffic, worked for two years by the contractors, and handed over to the Company.

In May, 1872, Mr. Cooper re-entered the service of the Buenos Aires Great Southern Railway as General Manager and Engineer-in-Chief. Ten years later the development of the Railway was such that the duties of the General Manager demanded his undivided attention, and consequently the charge of the Engineering Department was placed in other hands. Mr. Cooper retired in 1886, when he returned to England. From the beginning of 1887 to 1892 he acted as Engineer in London to the firm of Messrs. Lucas, Gonzalez and Company, contractors, among other works, for the construction of the prolongation and branches of the Central Northern Railway of the Argentine Government.

He visited the River Plate in 1890 as one of a Commission, with the Chairman and Secretary of the Central Argentine Railway Company, and again in 1894 was sent out by that Company to take charge of the railway during the visit of the General Manager to England. He also superintended the manufacture and sending out of the materials for the Central Produce Markets at Buenos Aires. He was a Director of the North-West Argentine, the Argentine Great Western, the North-Eastern of Uruguay, and the Central Argentine Railway Companies, and of the United River Plate Telephone Company and the Santa Fé Land Company.

Mr. Cooper died at his residence, Pencliffe, Alleyn Road, West Dulwich, on the 3rd April, 1902. He was held in high esteem for his ability and for his kindly disposition, and many a man in need received advice and assistance from him.

Mr. Cooper was elected an Associate of the Institution on the 2nd May, 1871, and was transferred to the class of Members on the 30th October, 1877.

WALTER MERIVALE, third son of the late Very Reverend Charles Merivale, D.D., Dean of Ely, was born on the 22nd of December, 1855. He was educated at Haileybury College, and thence passed into the works of Messrs. Black, Hawthorn and Co., Locomotive Engineers, of Gateshead-on-Tyne. During his apprenticeship he served six months with the Société John Cockerill, of Seraing, Belgium, and afterwards became a pupil of the late Mr. Alfred R. C. Harrison, on the North Eastern Railway. On the completion of his training in 1881, Mr. Merivale was employed by the West of India Portuguese Railway Company as Executive Engineer on the construction of the line, from the harbour of Mormugão to the Western Ghâts, which connects the ancient Portuguese possession of Goa with the Southern Mahratta system of railways in British India.[1] He was first engaged on the erection of machinery at the harbour, but was soon sent up country and employed on survey in the Sonauli Valley, a difficult and unhealthy district, possessing a native name equivalent to "The Valley of the Shadow of Death." With characteristic ardour he set himself at once to conquer all difficulties, and spared himself so little in the attempt that his strength gave way, and he soon fell a victim to the fever of the country, and must certainly have died but for the kindly care of the contractor and his wife, who brought him to their bungalow and nursed him back to life. A sea voyage to Australia completed the cure.

On his return Mr. Merivale was married in Bombay to Emma Magdalene, daughter of Mr. John Pittman, of the Civil Service, and, accompanied by his young wife, again took charge of the Sonauli, where his work had been thoroughly successful. A severe epidemic of cholera broke out in the following year among the natives, and he strained every nerve to help them through it, carrying brandy and chlorodyne to the sick, and burying the dead, often with his own hands digging their graves when their own people fled in fear. But a return of fever soon compelled his removal to the more healthy station of Karapani, where he remained till the conclusion of his engagement with the West of India Portuguese Railway in 1885. After a short holiday in England he returned to India on the staff of the Indian Midland Railway, first as an Assistant, and afterwards as a District Engineer, during which time he had charge of the Saugor Division.

In 1889 Mr. Merivale quitted India and undertook the survey

[1] For description of the line, *vide* Minutes of Proceedings Inst. C.E., vol. xcvii. p. 302.

of a projected line of railway in Costa Rica. His next move was to Barbados, where he held an appointment for five years as Manager of the Barbados Railway. There he threw all his energy and resourcefulness into the task of reviving the fortunes of the line, which had sunk very low by the depression of the sugar trade in the West Indies and the consequent failure of traffic. Mr. Merivale saw another possible source of profit in the *Manjak*, a species of asphaltum or glance pitch with which the island abounds, and obtained mining rights over a considerable area, which he worked with some success as long as he remained there. But on the expiration of his term of engagement the railway was taken over by another company, and Mr. Merivale left Barbados and went to Venezuela, where he undertook the management of the South-Western of Venezuela (Barquismeto) Railway. During his stay in that country he was attacked by a severe illness, the fruits of twenty years' hard work in tropical climates, and in the summer of 1901 he returned to England, hoping that a few months' rest at home would restore him to health and activity. He could not endure to be idle, and employed this time of enforced leisure in learning Dutch with a view to possible openings in South Africa. He had been also from time to time a contributor to the *Spectator* and other journals, and almost his last piece of work was to write a paper on Rack Railways and Steep Gradients for this Institution.[1] As the winter advanced his health failed more and more; and a chill caught early in February brought on another attack of illness from which he had not strength to rally. He died on the 14th February, 1902, aged 46.

Mr. Merivale was elected an Associate Member of the Institution on the 1st May, 1888, and was transferred to the class of Members on the 10th January, 1893. He was also a Member of the North of England Institute of Mining and Mechanical Engineers.

HENRY SADLEIR RIDINGS, born at Cork in 1839, obtained his preliminary engineering training at the Queen's University in Ireland, now the Royal University, where he obtained the diploma in Civil Engineering and the degree of M.A., with a gold medal for mathematics. After serving a pupilage with the late Mr. Joseph Fogerty, who was then Resident Engineer for Sir John Fowler, Past-President, on railway works in Shropshire,

[1] Minutes of Proceedings Inst. C.E., vol. cxlvii. p. 280.

he was engaged in 1864 and 1865, under the late Mr. O. C. D. Ross, on a section of the Utrera and Osuna Railway in Spain. In 1868 he was employed for a brief period in Bengal on government works in the Barrackpore Division, and on the Sone Canal and irrigation.

Having been obliged to relinquish work in India and return to England, owing to the death of his wife, Mr. Ridings was appointed in 1869 Resident Engineer of the Iquique Nitrate Railway in Peru, a mountain line of 70 miles, of which Mr. George Bush was the Chief Engineer. He held that post until 1878, when family affairs compelled him to resign. His work during the following nine years included the survey in 1883 of the Dique entrance to the Magdalena River in the United States of Colombia, the superintendence of works at East Greenwich in connection with the South Metropolitan Gas Company, and railway surveys in South Africa and in Mexico. From 1887 to 1890 he acted as Borough Surveyor of Walthamstow, and in the latter year he was again sent to Iquique by the Nitrate Railway Company as Resident Engineer on the construction of the southern section of the line. In 1897 he returned to England, and from that time was not engaged in professional work. Mr. Ridings died at 31 Carson Road, West Dulwich, on the 8th January, 1902, in his sixty-third year.

He was elected an Associate of the Institution on the 23rd May, 1865, and was transferred to the class of Members on the 24th November, 1874. In 1883 he presented a Paper descriptive of the Iquique Railway.[1]

WILLIAM ROBERT ROBINSON, who died at Crouch End, near London, on the 1st November, 1901, at the age of 69, was born at Tullamore, Ireland, on the 2nd February 1832, and came from a well-known Kerry family. He received his professional education at Queen's College, Cork, and at one time held a lieutenant's commission in the Kerry Militia. In 1857 he was employed on the survey and construction of the Tralee and Killarney Railway, under the late Mr. W. R. Le Fanu, and subsequently on the survey and final location of the Mallow and Fermoy extension.

Towards the end of 1858 Mr. Robinson went to India to join the engineering staff of the Madras Railway, and on his arrival was entrusted with the survey of the North West Line, which

[1] Minutes of Proceedings Inst. C.E., vol. lxxii. p. 185.

work he completed up to the Pennér River. In 1861 he was placed in charge of the 3rd District, the construction of which had been retarded owing to the great difficulty in retaining labour in the feverish tract of dense forest traversed by this portion of the railway; but Mr. Robinson successfully carried out the heavy earthwork and bridging on 25 miles of this section, part of which forms the well-known "Balapalli Ghat." The most important work, however, on which he was engaged was the fine girder bridge of fifty-eight spans of 70 feet, exceeding ¾ mile in length, over the Tungabadhra River, near Raichúr. The masonry abutments and piers, some of which are over 40 feet in height, were erected by contract under Mr. Robinson's supervision, and the excellent quality and substantial character of the work challenge comparison with similar structures in other parts of India.

In 1874 he acted as Deputy Chief Engineer on open line, in which post he was confirmed in 1875, and it was during his tenure of that appointment that he had a marvellous escape in the disastrous accident which befel his inspection train on the 16th June, 1874. When running at the speed of 60 miles an hour the train suddenly left the rails while crossing the Papaghni Bridge, and plunged into the dry bed of the river. Mr. Robinson and the Resident Engineer extricated themselves from the débris somewhat severely bruised, but the inspector, who was in the same compartment, and the two firemen on the engine were unfortunately killed. His nervous system, however, suffered so much from the shock that he was compelled to return to England on sick leave. In 1876, on his return to Madras, he was appointed Chief Engineer, which post he held until his retirement in August, 1889, and during that interval on more than one occasion he acted as Agent and Manager, and as the Company's representative in India. His long residence of nearly thirty-one years in the tropics, combined with the effects of the accident referred to, gradually told on a constitution otherwise robust and capable of enduring much hardship, and he finally succumbed to the insidious ailment which developed itself during the last few years of his life. In his younger days Mr. Robinson was a fearless rider, an ardent sportsman, especially after large game, and an enthusiastic angler, having devoted much attention to the habits of fish found in Indian waters. In private life he was held in high esteem by those who knew him well for his large-heartedness, his generous and cheerful nature, and his genial disposition. Mr. Robinson was elected a Member of the Institution on the 6th December, 1870.

WILLIAM STARLING, born on the 23rd of January, 1839, graduated in 1856 at the University of New York. His engineering knowledge was largely picked up in the United States Army, during the Civil War, in which he served as Lieutenant, Captain, and finally Major in the 9th Kentucky Infantry. With a wonderful gift for acquiring knowledge from books, he undertook engineering work in an emergency, and, studying as he worked, soon ranked with the engineers of the regular service, and during most of the war acted as Chief Engineer to the Fifth Division of the Twenty-first Army Corps. After the war he became a planter in Arkansas, and in 1882, having sold his plantation interests, he removed to Greenville and entered the service of the Mississippi Levee Commissioners. In 1884 he was appointed Chief Engineer of the Mississippi Levee district, which post he held for about twelve years. It was a mark of his personal popularity, no less than of his undoubted fitness for the position, that he was elected by a Board of Southern men—though he had served in the Northern Army—over two competitors, both of whom had been officers in the Southern or Confederate Army during the Civil War. Mr. Starling's latest professional work was as a Member of the South-West Pass Commission, formed to recommend a new channel through the Delta of the Mississippi at New Orleans. He spent much time abroad, principally in Holland, studying the system of dykes in that country, a description of which he contributed to the American Society of Civil Engineers.[1] He always referred in the kindest terms to the treatment he had received in England, and was one of the members of the American Society of Civil Engineers who visited this country in 1889 on their way to the Paris Exhibition.

Mr. Starling died on the 11th December, 1900. He was a man of great force of character, frank and cheerful in his intercourse with all.

He was elected a Member of the Institution on the 1st December, 1896.

FRANCIS STEVENSON, late Chief Engineer of the London and North Western Railway Company, died literally in harness in the seventy-fifth year of his age, after a devoted service of nearly fifty-nine years; and although his illness first confined him to his residence on the 10th January, he was able to give advice and

[1] Transactions American Society of Civil Engineers, vol. xxvi. p. 559.

attend to matters of business within a few days of his death, which took place on the 1st February, 1902.

His career was a notable one. He was born of an old Scottish family in August, 1827, and after receiving an education at the Edinburgh Academy he was articled, at the early age of 13, as a pupil to the late Mr. R. B. Dockray, then one of the engineers of the London and Birmingham Railway Company, and in 1843 he became a member of the engineering staff. He was engaged on the construction of the Northampton and Peterborough line, which was opened in 1845, and was also Resident Engineer on the Coventry and Nuneaton Railway, completed in 1850. Subsequently he was transferred to Euston, and in 1855 became assistant to the late Mr. W. Baker, whom he succeeded as Chief Engineer, in charge of all new works and parliamentary business, in January, 1879.

His extensive knowledge and experience of the past history of the great undertaking of the London and North Western Railway induced the Directors in 1886 to place under his charge, in addition to his other duties, the maintenance of the whole of the railway, of course with efficient assistants.

It is obvious that for a man to attain such a position his ability and integrity must be of the highest order; but it is not only from this point of view that his memory will be cherished. Under a retiring nature there was a deep substratum of sound common-sense, discrimination and sympathy, combined with a genial temperament, and his patient calmness and resource in circumstances of emergency, which sometimes happen on a great railway, were remarkable. Mr. Stevenson was an ardent lover of nature, with a profound veneration for ancient and historical buildings. When designing new work, whilst he kept in view the principles of reasonable economy, he was careful to so arrange his designs that they should leave undisturbed, as far as practicable, any prominent or pleasing feature in the vicinity. His geological knowledge was also of much service in dealing with the many important schemes entrusted to his judgment. His loss at Euston Station especially is much felt by the Directors and by his brother chief officers, with whom he came into daily contact. His staff also miss a firm friend and a chief who was at all times considerate, encouraging and just, and whom it was their constant pride to serve. He was well known in the vicinity of Westminster and in the precincts of the Committee Rooms of the Houses of Parliament, where he frequently met old acquaintances, to whom, in the interval of waiting for committees, he would relate, with

vivacity and humour, the many experiences of his life. One of his favourite stories was to relate how the late George Stephenson at one time was his assistant; and having made this statement, it afforded him amusement to observe the questioning look of his hearer. The story is that once at Coventry, when taking some measurements, George Stephenson held the ring at the end of the tape and he the box end, thus securing the measurement at his end of the tape, whilst George Stephenson was only assisting him to obtain it.

Mr. Stevenson was elected a Member of the Institution on the 5th February, 1867. Although his busy life prevented him taking an active part in the proceedings of the Institution, he held it in high appreciation, and impressed upon the younger members of his staff especially the desirability of joining its ranks.

JAMES PENMAN HUGH WALKER, son of Captain Robert Walker, R.N., was born at Windywalls, near Kelso, on the 7th April, 1834. After being educated at Kelso and Jedburgh, he served a pupilage of five years with the late Mr. John Murray. On the expiration of his pupilage he was employed under Mr. Murray from 1856 to 1858 as an assistant on the North Graving Dock and other works connected with the Sunderland Docks. In August of the latter year he was appointed an Assistant Engineer on the Great South of India Railway, which post he held until the autumn of 1862, when he entered the service of the East Indian Irrigation and Canal Company as an Executive Engineer on the weirs, canals and other undertakings connected with its irrigation works at Orissa. When the Company's works were taken over by the Public Works Department of the Government of India in 1869, his services were retained; and he subsequently became Superintending Engineer of the Orissa and the Sone Irrigation Circles.

Mr. Walker resigned his appointment in the Public Works Department, on account of ill health, in 1879, and from that time lived in retirement in England. He died at Sutton, Surrey, on the 11th January, 1902.

He was elected a Member of the Institution on the 1st February, 1876.

GEORGE SCHOLEY YOUNG, born at Stepney on the 17th February, 1850, was educated at Poplar Academy and at the City of London College. At the age of 16 he was apprenticed for five years to Mr. T. A. Young, Marine and Mechanical Engineer, of Orchard Place, Blackwall, and on the expiration of this pupilage he was employed by Mr. Young from 1871 to 1881, first as a draughtsman and subsequently as manager. In the latter year he became a partner and continued to be responsible for the management of the business, which included the design and manufacture of paddle-wheel, single-screw and twin-screw machinery, until 1891, when he was appointed Marine and Mechanical Engineer to the Thames Ironworks and Shipbuilding Company. In the same year he carried out, under the direction of Sir Alexander Binnie, the construction and fixing of the machinery for the precipitation works at Crossness of the London County Council.

When the Thames Ironworks Company took over the works of Messrs. John Penn and Sons in 1900, Mr. Young was appointed Engineer and Manager at Greenwich. There he was engaged in the design and manufacture of machinery for battleships for the British Admiralty. He also designed and erected the Company's shops at Greenwich and Deptford for the manufacture of Belleville boilers, and was the inventor of the Thames Ironworks water-tube boiler. Shortly before his death he carried out an interesting series of experiments on lubricating appliances in connection with marine engines. Mr. Young died at his residence, 9 Blessington Road, Lee, on the 11th February, 1902.

He was elected a Member of the Institution on the 4th December, 1900.

HENRY HARINGTON LEIGH, born in Jersey on the 9th November, 1858, was the eldest son of the late Rev. Francis J. Leigh, for many years Rector of Nympsfield, near Stroud, in Gloucestershire, and subsequently Vicar of Buckland, near Faringdon, in Berkshire. After being educated at the Cathedral School, Worcester, at Blackheath Proprietary School, and at the Crystal Palace Engineering School, he was articled in 1877 to Mr. John Waugh, of Bradford, with whom he remained for some time after the completion of his pupilage, being engaged among other works on the construction of the Winter Garden at Morecambe. In 1879 he went to sea as an engineer in the service of Messrs. Green, and in April, 1882, he entered into partnership with Mr. J. F.

Phillips, as engineers and patent agents, with offices in Southampton Buildings, Chancery Lane. That partnership was dissolved in May, 1884, since which time Mr. Leigh carried on the practice alone, until his death, at Holmlea, East Molesey, on the 22nd July, 1901.

He was elected an Associate Member of the Institution on the 6th December, 1887.

ALFRED JAMES LINNELL, eldest son of Mr. James Thomas Linnell, of Redstone Wood, Red Hill, the well-known artist, was born on the 5th October, 1866, and was educated at Marlborough and in the Applied Sciences Department of King's College, London. After serving articles with Professor Henry Robinson, he was employed by Messrs. J. G. Meiggs, Son and Company, from July, 1889, to January, 1891, on the surveys for the Port of Santa Fé, for the Railway in connection therewith, and for the line from Ramirez to Diamante in the province of Entre Rios. In March, 1891, he was engaged by Messrs. Eckersley, Godfrey and Liddlelow to assist in the survey for the Piraeus-Larissa Railway, and from 1896 to 1898 he was employed for Sir John Jackson on the Keyham Dockyard extension. In the autumn of 1899 he was appointed by Messrs. Coode, Son and Matthews as Assistant Engineer, under Mr. J. H. Bostock, to take charge of the Graving Dock and other works in connection therewith at Colombo Harbour, Ceylon. Unfortunately he fell a victim to an attack of typhoid fever, his death taking place on the 21st January, 1902. Mr. Linnell was an enthusiastic and most promising engineer, and secured the respect and affection of all who worked with him.

He was elected an Associate Member of the Institution on the 1st December, 1891.

THOMAS THOMAS MARKS, born on the 18th February, 1845, obtained his early training under his father, who carried out various contracts on the South Wales division of the Great Western Railway. From 1865 to 1870 he was employed in the service of the Swansea Corporation, and in the latter year he was appointed Surveyor to the Lowestoft Improvement Commissioners. In addition to the usual duties of that post, he carried out, under

the direction of Mr. Peter Bruff, an outfall sewer into the sea at Ness Point. In 1876 Mr. Marks was appointed Clerk and Surveyor to the Llandudno Board of Commissioners, and under his superintendence the Llyn Dulyn water-supply, the new gasworks, and many town improvements were carried out. He resigned that post in 1891 and went into private practice. Mr. Marks was a member of the Llandudno District Council, of which he served the office of Chairman in 1898–99. He died on the 19th September, 1901.

Mr. Marks was elected an Associate of the Institution on the 3rd December, 1872, and was subsequently placed in the class of Associate Members.

JOHN PATERSON died at his residence, Parade House, Fort William, on the 23rd October, 1901, at the age of 56. Born at Inverness on the 25th September, 1845, he was educated at Dollar Academy, where he obtained a medal for mathematics. He obtained his early professional training as a pupil of the late Mr. Joseph Mitchell, of Inverness. In 1865 he was appointed, after examination, an Assistant Engineer in the Public Works Department of the Government of India. He officiated as Executive Engineer from October, 1872, and practically from that date held independent charge till 1876, when he was promoted to the rank of Executive Engineer. Among the works on which he was engaged in India may be mentioned the South Pergunnah Roads, the roads in Southalia, and the Rhaugulpore Central Jail, which he constructed in conjunction with Major G. H. Hills, R.E. In carrying out these and other works, he appears to have shown engineering skill, energy and tact in organising labour, and efficient supervision.

On the reduction of the Bengal Public Works Department, Mr. Paterson retired with a pension and bonus in 1879. After leaving India he was employed for some time on professional work in Barbados, and subsequently in the North of England on Lord Bolton's estates. In 1883–84 he was engaged on the Parliamentary survey of the Inverness and Aviemore Railway, and thereafter acted as Resident Engineer of the Keith and Buckie Railway, and the branch line to Strathpeffer Spa; and in 1885 he was employed in staking out the southern section of the Inverness and Aviemore Railway, surveying and taking levels, and preparing the working

drawings under the late Mr. Murdoch Paterson, Chief Engineer to the Highland Railway. In 1889, Mr. Paterson was appointed Road Surveyor to the Lochaber District Committee, and Burgh Surveyor to the Town Council. There, in concert with Mr. R. F. Yorke of Glasgow, he assisted professionally in the introduction of electric light for the town. His services were often in request in arbitration cases in connection with railways.

Mr. Paterson devoted some of his spare time to literary work, and was the author of an article in *The Engineer* of the 10th August, 1900, on "Testing Cement by the Modulus of Rupture for Transverse Strain." In 1886 he published "Tables and Diagrams of Switches and Crossings, showing Lengths, Leads, and Radii of Curves at Connections," which has passed through four editions. A genial and loyal friend, no one could know him long without recognising his great ability, and at the same time without being struck with the true modesty which dominated his undoubted intellectual gifts.

Mr. Paterson was elected an Associate Member of the Institution on the 2nd December, 1879.

JAMES PONSFORD, fourth son of the late Mr. William Ponsford, of Gloucester Terrace, Hyde Park, was born in 1840, and was educated at the Cathedral Grammar School, Rochester, and privately by the Vicar of Rolvenden, Kent. In 1856 he was articled as a pupil to the firm of Messrs. Thomas Richardson and Sons, engineers and shipbuilders, of Hartlepool, and on the completion of his pupilage in 1861 he became a draughtsman in the works of Messrs. Palmer Brothers, of Jarrow, Newcastle-on-Tyne. After remaining at Jarrow for two years, he came to London in 1863, and was employed by the late Mr. Anthony Ritson, the contractor, on the Temple section of the Victoria Embankment, and on the Midland Railway extension into London.

In 1867 Mr. Ponsford was appointed Assistant Locomotive Superintendent on the Varna and Rüstchück Railway in European Turkey, and from 1871 to 1874 he acted as Chief Mechanical Engineer on the Salonika and Uskup line of the Ottoman Railway Company. In 1874 he entered the service of the Turkish Government as Chief Mechanical Engineer of the Scutari-Ismidt Railway in Asiatic Turkey, which post he held for seventeen years, until that line was absorbed by the present Anatolian Railways system under German control. In recognition of his services the

Sultan conferred on him the Medjidieh of the Fourth Class. During the last ten years Mr. Ponsford lived at Cairo, and at the time of his death, which took place on the 2nd January, 1902, he was engaged in maturing a scheme for irrigating a considerable tract of land a little distance from Cairo. He left a widow, the sister of General Sir Edward Zohrab Pasha, Egyptian Under-Secretary for War, two sons, and a daughter.

Mr. Ponsford was elected an Associate Member of the Institution on the 2nd December, 1879.

CHARLES LOUIS NAPOLEON WILSON, born in Blackburn on the 28th August, 1865, served his pupilage in the office of the Borough Engineer of Bacup. After remaining in the office for five years as an Assistant, he was appointed Town Surveyor of Bilston in 1891. During the ten years he held that post he carried out several works for the improvement of the town, including the erection of technical schools, baths and other buildings. In the autumn of 1901 he tendered his resignation to the Bilston Council and proceeded to South Africa, where he died on the 15th November at Chinde from enteric fever contracted on the voyage.

Mr. Wilson was the author of a book entitled "Seven Years in a Black Country Town." He was elected an Associate Member of the Institution on the 6th December, 1892.

ROBERT GEORGE YOUNG, Resident Engineer of the London County Asylum, Colney Hatch, died on the 10th January, 1902, after a long and painful illness. In the autumn of 1900 he underwent a serious operation, which afforded temporary relief, and served to prolong his life for more than a year, but the nature of the disease did not admit of any hope of permanent improvement. His sufferings were borne with great patience and fortitude, and he continued to attend to his duties almost to the last.

Mr. Young was born on the 15th August, 1849, at Birkenhead, and after serving an apprenticeship to his father, who owned the Falcon Ironworks, Liverpool, he was employed by Messrs. H. Pontifex and Sons for several years in designing and in superintending the erection of machinery for various breweries and

distilleries. Subsequently he acted as Assistant to Professor John Perry in designing and superintending the extension of the works of Messrs. Latimer Clark, Muirhead and Co., of Westminster. In 1880 Mr. Young joined the Engineer's Department of Colney Hatch Asylum, which at that time belonged to the County of Middlesex, and in 1886 he succeeded the late Mr. R. Hack as Resident Engineer. The Asylum, which has a population of about 2,800, possesses an independent supply of gas and water, and until recently it had a separate sewage system. There is also a large laundry in which the washing is done by machinery. The building was erected more than fifty years ago, and in addition to the extensive repairs which are constantly required, important structural alterations and improvements have been carried out in the wards; the sanitary arrangements have been entirely reconstructed, and a system of heating has been provided throughout the building. A few years ago it became necessary to provide further accommodation for 300 additional patients, and iron buildings were erected for their reception. It will thus be seen that Mr. Young's position was an arduous and responsible one, and afforded him an opportunity of utilizing his knowledge of many different branches of the profession.

He was elected an Associate of the Institution on the 21st May, 1889.

SIR JAMES TIMMINS CHANCE, BART., M.A. (Cantab.), died at his residence, Grand Avenue, Hove, on the 6th January, 1902, in his eighty-eighth year. The eldest son of Mr. William Chance, a leading merchant and manufacturer of Birmingham, he was born on the 22nd March, 1814, and was educated at Mr. John Wood's school at Totteridge, and at University College, London, where he obtained high honours in languages, mathematics, natural philosophy and chemistry. At the age of seventeen he entered his father's mercantile business, but, finding the work distasteful, read classics and Hebrew with the view of taking holy orders. In 1833 he went up to Trinity College, Cambridge, and there made mathematics his chief study, gaining a foundation scholarship, and graduating as seventh wrangler in 1838, after losing a year through insomnia brought on by overwork. He had in the meantime changed his views as to a profession, entering as a student of law at Lincoln's Inn, but in the end circumstances obliged him, immediately after taking his degree, to join his uncle and father

in their glass works at Spon Lane, near Birmingham, where the former had introduced the manufacture of sheet glass from abroad some eight years before. At Spon Lane he still refused to have anything to do with the commercial side of the business, devoting himself to the manufacturing and to scientific developments. Already while at Cambridge he had invented a process for polishing sheet glass to produce "patent plate," the machinery and engines for which remained in use after sixty years.

But the principal work of his life was upon dioptric apparatus for lighthouses. This difficult manufacture had been carried on in England from 1831 to 1845 by Messrs. Cookson & Co., of South Shields, but when they relinquished it, it became again the monopoly of two Parisian firms. About the year 1850 Messrs. Chance Brothers & Co. undertook it, engaging for its superintendence Mr. Tabouret, who had been employed for thirty years in the lighthouse department of the "Ponts et Chaussées," and had worked under Augustin Fresnel, the great inventor of the dioptric system. He constructed the first-order apparatus shown by the firm in the Great Exhibition of 1851; but he left in 1853, and not much further was done till 1855, when Messrs. Chance largely extended their plant, and began to send lights to all parts of the world.

Mr. James Chance, as chief manufacturing partner, had a great deal to do with this, but he only began to give his full attention to the work after the appointment in 1858 of a Royal Commission to inquire into the state of the lights, buoys and beacons of the United Kingdom. The reason was that, till the reform which resulted from the labours of the Commission, the manufacturer simply made the lenses and prisms to strict specifications, and no original work or invention was demanded of or allowed him. But the Commissioners speedily discovered that the existing dioptric apparatus in England and in Ireland, erected on faulty rules, was inefficient, wasting on the sky and nearer sea a great portion of the light which should have been directed to the horizon. In December, 1859, they visited Spon Lane, and made a thorough examination of all that they found there, under the guidance of Mr. James Chance, who placed with enthusiasm his mathematical and technical knowledge at their disposal. As the result of the discussions which took place, they requested his "individual and special" attention to the points of their inquiry, and expressed the desire that the Astronomer-Royal, Professor (afterwards Sir George) Airy, should go to Birmingham to compare views with him. Airy took up the work with the greatest zeal, had several

interviews with the Commissioners, with Mr. Chance, with Professor Faraday (for the Trinity House), and others, inspected a number of lighthouses, and paid an exhaustive visit to Spon Lane on 2nd and 3rd April, 1860, devoting particular attention to a large apparatus under construction for the Government of Victoria. He wrote to Mr. Chance on 28th June:—

"I conjecture that a rule of adjustment was laid down in the first instance—in France, I suppose—which has been closely followed everywhere; and that that rule is wrong. I very much wish that I could induce you to look at the Whitby Lights. I think that it would lead to an extensive and beneficial revolution in lighthouses."

Airy's work resulted in the proposition of new principles, which were tried first upon a first-order apparatus building at Spon Lane for the Russian Government, upon which he and Mr. Chance could work uncontrolled. Then, mainly owing to Airy's insistence, Mr. Chance was instructed by the Trinity House to institute experiments at Whitby Southern Lighthouse, the apparatus for which had been made by his firm. This work was carried out in conjunction with Professor Faraday in September and October, 1860, and the latter wrote subsequently:—

"All the time we were at Whitby (8 or 9 days) Mr. Chance and myself were occupied in learning, practising new methods of adjustment and correction, and using new instruments; and I cannot say too much in thanking Mr. Chance for the earnest and intelligent manner in which he has wrought with me in the experiments, working and thinking every point out. The method of adjustment is now so perfect that the authorities can hardly require more accuracy than the manufacturer can insure."

And when the Commissioners and a deputation from the Trinity House had made their examination of the experimental panels, Mr. Chance was invited to proceed with permanent alterations to the light on the new principles, and at once did so. At the end of November and early in December further experiments were conducted at Spon Lane, resulting in the victory of the new ideas.

One thing discovered at Whitby—and the discovery was due to obscuring of the horizon by haze—was that for the method of adjustment by "internal observation," a common-sense method now rescued from oblivion, it was not necessary to see the horizon itself, but that a graduated staff at a short distance from the lighthouse might be used to represent its direction. The importance of this discovery lay in the fact that it enabled an apparatus to be accurately adjusted before it left the manufactory.

In January, 1861, Mr. Chance sent in to the Commissioners an elaborate Paper upon all the questions at issue, which is printed

in their Report. Upon receipt of it their chief, Admiral Baillie-Hamilton, wrote to him as follows:—

"I was reluctant to leave this office last night without having written to thank you, and to express my admiration of the Paper you have supplied us with. If the time and labours of the Commission had had no other end, it would have been sufficiently answered in their having led to the earnest application of your talents and your time to a subject of the very last importance as regards the science of lighthouse illumination, to be mastered as that subject has been by you. Scientific men may be more minutely conscious than myself of all the value of your work, and at any rate it will stir the minds and mettle of many of them; but as even I am able to understand every axiom as well as the whole theory contained in your clear and complete treatise, I can yield to none in appreciating its merits, and in the feeling of satisfaction at its being thus given to the world."

The next apparatus to be constructed upon the new principles was one for the Smalls Rock, near Milford Haven, the completion of which had awaited the results of the experiments. It was finished towards the end of 1860, and was reported upon by Faraday most favourably. In May, 1861, the Trinity House formally requested Mr. Chance to help them in a proposed examination of all the dioptric apparatus under their charge, and in the execution of any changes that might be necessary. He agreed willingly, and in June aided in the inspection of several Welsh lights. The first alterations were made at the North Foreland to a French apparatus in extremely bad order. Next were set right those at the South Foreland, at St. Catherine's in the Isle of Wight, at Whitby North, and at St. Ann's, Milford Haven; in 1862 at Orfordness, the Skerries, Bardsey Island and Lundy Island; and in 1864 at the Bishop Rock, the Needles, the Eddystone, Spurn Head and Trevose Head. Ten Irish lights also were attended to. Most of these were of French manufacture, and the defects of some could only be remedied by entire reconstruction. All this work was carried through by Mr. Chance personally; he made indeed most of the final adjustments with his own hands.

The reputation which he gained had important results. While up to the year 1860 Messrs. Chance had no control over the instruments they made, now matters were placed on quite a different footing. Informed of the class of apparatus wanted, and of the requirements of the locality, Mr. James Chance was left to design the light himself, and to produce it as a whole, except in the cases of the Scottish Lighthouse Board and the lighthouse authorities of Japan and New Zealand, where Messrs. Stevenson still continued to furnish Messrs. Chance and other manufacturers with the designs of the optical apparatus required for those services. His productions were uniformly successful, and greatly increased the

reputation of his firm. The most important of them in the years 1862 to 1864 were for the Hanois Rocks in Guernsey, for Innistrahul in Ireland (shown at the Exhibition of 1862), for Great Orme's Head, for the Mauritius, for Riga, for Robben Island, Cape of Good Hope, for the Hook Tower near Waterford, for Sedashegur on the Bombay coast, for Double Island in the Bay of Bengal, for Terschelling Island in Holland, and for Europa Point, Gibraltar. Mr. Chance's success was the outcome of his personal superintendence of every detail of the work. He devoted to it all the time he could spare from other pressing business, was at the works night after night as well as in the daytime, and when at home was deeply engaged for hours together in solving the novel and intricate problems which presented themselves, and in working out the mathematical calculations required for each new design. Fresnel's formulas he re-calculated and reduced to working shape. He was interested in the work for its own sake, and a chief ambition was to render England independent in a matter so vital to her commercial interests. In the same spirit he would never patent the improvements he introduced, but left them to be public property. It would be out of place here to detail the various productions of the twelve years which he devoted to lighthouse work. His crowning triumph came at the Paris Exhibition of 1867, when the instruments of his design were proved by scientific tests to be superior in efficiency to the corresponding apparatus of French manufacture. The chief of them were two first-order apparatus, and one of the third order for use with the electric light.

In the same year he read before the Institution of Civil Engineers a remarkable Paper on "Optical Apparatus used in Lighthouses,"[1] which has become a classic. For that Paper he was awarded a Telford Medal and Premium. In 1879 he read a second excellent Paper "On Dioptric Apparatus in Lighthouses for the Electric Light."[2]

About the year 1872 Mr. Chance relinquished the direction of the lighthouse works to the late Dr. John Hopkinson, Member of Council, then fresh from his brilliant career at Cambridge. Continuing for some years to take the chief part in the general management of the firm, he gradually retired from this also in favour of its younger members.

Mr. Chance was a Justice of the Peace for the counties of Stafford and Worcester, and a Deputy-Lieutenant of the former from 1856,

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[1] Minutes of Proceedings Inst. C.E., vol. xxvi. p. 477.

[2] *Ibid*, vol. lvii. p. 168.

and of the latter from 1859. He served the office of High Sheriff of Staffordshire in 1868. He was a Governor of King Edward's School, Birmingham, from 1845 to 1879, a Director of the London and North Western Railway from 1863 to 1874, and a Member of the Council of University College, London, from 1880 to 1891, having been a Life-Governor thereof since 1874. Without further reference to the educational and philanthropic work to which he devoted much time and money, it may be recorded that in the year 1900 he endowed, at a cost of £50,000, the "Chance School of Engineering" in the University of Birmingham. He married in 1845 Elizabeth, fourth daughter of Mr. George Ferguson, of Houghton Hall, Carlisle. He received his baronetcy on the occasion of the last distribution of Birthday Honours by the late Queen.

He was elected an Associate of the Institution on the 21st May, 1867.

SIR THOMAS LUCAS, BART., died on the 6th March, 1902, in his 80th year. Born in 1822 he was the son of Mr. James Lucas, and brother of the late Mr. Charles T. Lucas, of Warnham Court. The latter was the first to enter business, as a builder, in partnership with his father; the subject of this notice subsequently joined his brother, and the firm of Lucas Brothers came into existence. Commencing in the eastern counties, with large works at Lowestoft, they undertook extensive operations in the development of that town; the construction of waterworks at Norwich and Yarmouth; and the building of country houses, Somerleyton, Henham, and Rendlesham, amongst others. Moving from Lowestoft to London, Lucas Brothers secured premises by the riverside in Lambeth, and entered upon a long series of undertakings of public interest and importance; the most notable buildings belonging to that period are the stations and hotels at Cannon Street and Charing Cross, the Royal Italian Opera House, the Albert Hall, the South Kensington Exhibitions of 1867 and 1871, the Alexandra Palace, the Junior Carlton Club, and some private houses, including Cliveden. They were responsible for Government work of varying magnitude; the reconstruction of Woolwich Arsenal and of Colchester Camp, besides work at Aldershot, Shorncliffe and elsewhere; and the provision of huts for the troops in the Crimea, for which they received the special thanks of the Government. In some instances they were associated with other leading builders and contractors, such as the

Brasseys, Sir Morton Peto, Mr. Wythes, and Sir John Kelk, in conjunction with whom they erected the Exhibition Buildings of 1862.

In 1874 arrangements were made for taking into partnership Mr. Aird, now Sir John Aird, Bart., M.P.; and under the style of Lucas and Aird, and John Aird and Sons, the new firms were heavily engaged in all directions on railways, dock and harbour construction, and gas- and waterworks, the Hull and Barnsley Railway, the West Highland Railway, besides work for most of the principal railway companies. The Tilbury and Royal Albert Docks, and numerous dock extensions, belong to the ensuing period; and it was to Lucas and Aird that the tentative scheme for connecting Suakim and Berber by railway, in 1885, was entrusted. Mr. Charles T. Lucas and his brother both retired from business during their lifetime, after a partnership of half a century, during which small beginnings had grown through strenuous efforts into a record of remarkable achievements.

Sir Thomas Lucas was twice married: first to the daughter of Mr. Golder of Folkestone; secondly to the daughter of Mr. Chamberlin of Catton, near Norwich. At one time he was much interested in the volunteer movement, and in the eastern counties took an active part in its encouragement. He was subsequently Major and Honorary Lieut.-Colonel in the Engineer and Railway Volunteer Staff Corps, and received the volunteer decoration. On one occasion he was called as a witness before a committee sitting at the Horse Guards, on the question of reserves and terms of service, and was requested to supply the members with a memorandum of his views. Sir Thomas Lucas's career was undoubtedly modified by the result of a trifling railway accident. A blow on the knee resulted in a peculiar affection which baffled all the resources of surgery, and during the last forty years of his life left him a constant sufferer, and in the end a confirmed invalid.

He was an ardent politician, and with better health would have probably taken a more active part in public life. He was intimately concerned with the schemes for erection of artisans dwellings, elaborated by the present Lord Cross during Lord Beaconsfield's last administration; and was consulted on subsequent occasions as to constructive work contemplated by Government. He was a member of the Carlton Club, and in 1887 his long association with public and political enterprise was recognised by the bestowal of a baronetcy.

Sir Thomas' home was at 12A Kensington Palace Gardens, where he took continual pleasure in the pictures and objects of

art which he had collected during many years. In 1880 he purchased Ashtead Park, in Surrey, but this he sold in 1888; recently he bought the property known as Heatherwood at Ascot, which became his summer residence.

For many years he spent the winter on the Riviera, and was a familiar visitor at Cannes, where he specially interested himself in St. George's Church, the memorial of the late Duke of Albany. He was associated with many charitable institutions, and was the patron of the Living of Ashtead. Ill-health compelled Sir Thomas at all times to lead a retired life; his principal recreation was the Opera, at which he was a regular attendant for many years; but latterly he was forced to entire seclusion.

He was elected an Associate of the Institution on the 6th December, 1864.

*** The following deaths have also been made known since the 21st April, 1902:—

Members.

ATTOCK, FREDERICK; *died* 21 May, 1902.

BUCHANAN, GEORGE; *died* 3 May, 1902.

HUTTON, WILLIAM RICH; *died* 12 December, 1901.

LEVENTHORPE, ALGERNON; *died* 3 July, 1902.

LOGAN, ROBERT PATRICK TREDENNICK; *died* 26 April, 1902.

McMORDIE, DAVID, B.E. (*Queen's*); *died* 11 February, 1902.

O'CONNOR, CHARLES YELVERTON, C.M.G.; *died* 10 March, 1902.

SHAND, JAMES; *died* 10 June, 1902.

SLEATER, JOHN MONTGOMERY; *died* 6 May, 1902.

TRUMAN, ARTHUR SMITH; died 6 June, 1902.

Associate Members.

ALEXANDER, FRANCIS GEORGE, B.A.I. (*Dubl.*); *died* 17 April, 1902.

BEAHAN, JOHN CHARLES; *died* 10 February, 1902.

CLEGG, BENJAMIN; *died* 21 February, 1902.

FOX, WILLIAM HENRY; *died* 24 May, 1902.

TOCKE, ALFRED REGINALD; *died* 15 January, 1902.

Associate.

COLLINSON, THOMAS BERNARD, *Major-General* R.E. *retired; died* 1 May, 1902.

Information as to the career and characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 4 July, 1902.

SECT. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

Unsettled Questions in Railway Practice.

(Organ für die Fortschritte des Eisenbahnwesens, 1901, p. 246.)

The German Railway Union are at present making an effort to arrive at conclusions regarding a great number of unsettled points connected with the engineering side of railway work. The questions are in the first instance framed and sent in to the technical committee by the various railways within the Union. The Committee sifts these questions, striking out some and remodelling others, and finally sends the resulting list of questions to all those concerned. In the present instance there are ninety-six questions, and the reporting on the answers is undertaken by numbers of the different railways. For example, the Hungarian State Railways are to report on the answers to seven of the total number of questions, the Dutch Railway Company on three, and so on.

Group No. I. concerns the construction of open line, and the various questions, each of which consists of several paragraphs, deal with the material, form and method of fixing the rails, the material and stresses in iron bridges, tunnels, and the ventilation of them, culverts and level crossings. Group No. II. contains eight questions dealing with stations. Group No. III. is extensive and is devoted to locomotives and tenders. The remaining groups contain questions as to rolling-stock, workshops, working of the traffic and signalling.

In connection with the materials used in railway structures, the questions dealing with rails and bridges ask for evidence regarding the application of the three different kinds of steel—Martin, Bessemer (acid), and Thomas (Bessemer-basic)—and also as to the employment of wrought-iron for bridges. Another group asks for experience with bridges and culverts constructed of concrete—plain, and reinforced with iron.

The locomotive group of questions contains eleven paragraphs devoted to compound locomotives and the use of superheated steam. The section of signalling contains one set of questions asking for the results of experience with the working of signal cabins by power: (*a*) electric current, (*b*) compressed air, (*c*) combination of electricity and compressed air, and (*d*) hydraulic power.

J. G.

The Montreux Bernese Oberland Railway.

(Schweizerische Bauzeitung, 1901, p. 224. Plans.)

For some years past the construction of a railway to connect the Lake of Geneva with the Lake of Thun through the Pays d'en Haut has been considered necessary. The Author describes the local conditions and the great increase in the tourist traffic, and then deals with the actual course finally selected for the new line. One terminus is close to the existing station of the Jura-Simplon railway at Montreux; the line then rises to Les Avants, descends to Montbovon, then rises again to Saanen-Möser and descends to Zweisimmen; the total length is about 37·2 miles, and it is of metre gauge. At Saanen Möser the elevation of the line is 4,208 feet above sea-level. Between Montreux and Montbovon the ruling gradient is 6·7 per cent. and the least radius of curves 131 feet, but from the latter point to Zweisimmen the gradients do not exceed 4 per cent., and the least radius of curves is 262 feet. On the first section there is a total length in tunnel of 3,270 yards, one tunnel alone being 2,649 yards long. On the second section are shorter tunnels with a total length of 452 yards.

The chief generating plant is to be at Montbovon, with small stations at Montreux and Zweisimmen; the rolling stock will consist of motor cars each weighing 21·5 tons and fitted with 4 motors each of 35 HP.; there will also be trailers weighing 12 tons and goods wagons carrying 10 tons. A steam locomotive is also provided for heavy goods traffic, and to assist in case of accidents. The line is designed for overhead conductors, and, owing to the heavy gradients and consequent variations in speed, direct-current has been selected so that battery storage may be employed.

For the Montreux-Zweisimmen section 4 transformer stations are used, and 3-phase current at 8,000 volts is transformed to direct-current at 750 volts. The central station has a capacity of 2,000 HP., or 2,500 with the aid of the batteries. The Author then gives details of the plant in the sub-station. At present it is not definitely decided whether the Company will generate their own current or not. It was expected that a part of the line would be opened last year, and that the whole work will be completed by 1904.

The estimated cost of the whole line is £469,000, or about £13,185 per mile. E. R. D.

The Barmen Rack Railway. DAUBNER.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 8.)

This Paper is descriptive of the system of railways which had its first beginning with the Barmen Mountain Railway. This line begins in the city of Barmen, and surmounts a height of 170 metres

(558 feet) in a length of about 1 mile, the average gradient being thus 1 in 9¾. The steepest gradient is 1 in 5·4, the sharpest curve 150 metres (492 feet) radius. The line is double throughout, and the gauge is 1 metre (3 feet 3⅜ inches). The other parts of the system are formed by two light railways and two systems of tramways, the total length being about 22 miles. The motive power for all the lines is electricity, derived from one central station. In this station there are four shunt-wound direct-current steam dynamos. Two of the engines are of 500 HP. and two of 1,000 HP. Under normal load the 500-HP. engines consume 7·4 kilograms (16·3 lbs.) of steam per HP. per hour, the 1,000-HP. engines 6·5 kilograms (14·3 lbs.) per HP. per hour. The dynamos are remarkably free from sparking, and have a high efficiency with a comparatively low rate of revolution. Buffer batteries are provided, having a capacity of 750 ampere-hours, the extra pressure to charge them being obtained from a motor dynamo which can raise the electrical pressure by from 40 to 175 volts. The line conductors are carried overhead; the feeders, underground on town lines and overhead on country lines, as bare conductors insulated.

Of the rolling stock for the rack railway there are two chief classes of passenger vehicles, a heavy 14-ton carriage for 36 passengers, provided with two 60-HP. shunt-wound motors and a smaller 11-ton carriage for 24 passengers with one motor of 85 HP. The shunt-wound motors have given perfect satisfaction in working. The armatures of the two motors on the larger vehicles are connected in parallel, the fields in series.

When going down hill at full speed, the motors return through the conductors 55 per cent. of the energy required on the journey up hill; thus while the heavy carriages use up on an average 11 kilowatt-hours of energy on the up journey, they return 5·6 kilowatt-hours on the down journey, so that for the double journey (2 miles) the carriage carrying about 12 passengers only requires an expenditure of energy of 5·4 kilowatt-hours.

The Paper contains a number of general views, diagrams and drawings. J. G.

The Wire Rope Railway in the Rigi Quarter at Zurich.

H. Schleich.

(Schweizerische Bauzeitung, 1901, p. 169. Three Figs.)

The town of Zurich has within recent years greatly extended, and the lower slopes of the Rigi are covered with villa residences, to which access is obtained by serpentine roads having gradients of 6 per cent. to 7 per cent., the slope of the land itself being 20 per cent. In 1885 a scheme was prepared by Mr. Ruge for a mountain railway to rise from the station bridge to the plateau

above the Hochstrass, but as yet only the lower portion has been constructed as a cable railway from the Limmat quay to the Polytechnic. The Author then describes how the Geissberg district has been built upon and various tramways made. In the year 1898 a concession was obtained for a cable railway along the Geissbergweg, and this work was completed in 1900; the gauge is one metre, and electricity is used for the motive power, as the system of working with water ballast in the descending car has not proved so satisfactory.

The line has a single track with a passing loop in the centre, the total length measured on the slant is 324 yards, the difference in level between the two ends is 239 feet, and the gradient varies from 20 per cent. to 33 per cent. It was impossible, owing to the contour of the ground, to obtain a parabolic profile for the line, although this would have been the most economical profile for power, as the rope is then properly balanced. In the lower part, the line is in cutting, but at the upper end upon an embankment. The rails are 32·8 feet long and weigh 47 lbs. per yard. The bridge which carries the railway over the Hadlaub road is built of concrete and steel on the Hennebique system. It has three spans of 39·36 feet and one span of 29·52 feet. The total cost of the bridge was £400, which is less than the cost of a steel girder bridge of the usual type. It weighs about 16,100 lbs. per lineal foot, and the cars weigh 8 tons. Tests of the loaded bridge were made and proved the structure was satisfactory. Further tests were made of the adhesion of concrete to wires, and it was found that rods of 1·12 inches in diameter, embedded in concrete for a length of 8·28 inches, had an adhesion of 213·3 lbs. per square inch of surface. The wire rope is driven by electric power, energy being supplied from the Dowson gas plant at the Zurich mountain railway generating-station at the rate of 1·9*d.* per kilowatt-hour. The motor develops 55 HP. with 500 volts at 700 revolutions per minute. The total cost of the entire work was about £10,400, and the line was opened in April, 1901, and has since worked satisfactorily.

E. R. D.

Improvements in Permanent-Way on the Andalusian Railways.

E. N. Beltram.

(Revista de Obras Públicas, 1901, p. 167. Five Figs.)

In France until recently Baltic fir sleepers had been used upon the main lines of railway almost entirely; attempts had been made to use the pine grown upon the Landes, but the character of the timber proved too soft. Mr. Albert Collet, of the Paris, Lyons, and Mediterranean Railway, however, invented a threaded treenail made of hard wood, and these were screwed into the sleepers, and the coach-screws then screwed into the treenails, and very

satisfactory results were obtained. The Andalusian Railways have now followed this example, and are using sleepers made of pine from the Landes and also from Segura, and have found very satisfactory results, as the timber is very much cheaper than that from the Baltic. In the original Paper views of the rail and sleeper are given, showing full details with dimensions. The rails used weigh 58 lbs. per yard, and are of the Vignoles section. They rest upon special plates the full width of the sleepers, and the coach-screws pass through holes in these plates, which rest directly on the screwed treenails.

The sleepers are injected with sulphate of copper or with creosote, and after 7 years' or 8 years' service it has been proved that the useful life of the sleeper has been increased 33 per cent. for beech, 62 per cent. for oak, and 80 per cent. for pine. Sulphate of copper being cheaper than creosote is more largely used, and the treenails keep the coach-screws from contact with the injected wood, which is an advantage. It appears that a large number of experiments were made to determine the best sections of thread for the exterior of the treenail and also for the coach-screw, and those finally adopted are such as to afford the same resistance against extraction for the treenail and the coach-screw; the threads are illustrated in the original.

E. R. D.

The New Railway Station at Seville.

(Revista de Obras Públicas, 1901, p. 182. Two photographs, three plates, three Figs.)

The new passenger station of the Madrid Saragossa and Alicante line at Seville was opened for public service in March 1901, and took the place of the temporary erection which had been in use since the opening of the line from Cordova to Seville. It is situated on the Plaza de Armas, the first design was prepared in 1889 by Mr. Süss, the engineer, now manager, and the actual detailed designs have been prepared and carried out by Messrs. Silva and Latona, engineers of the line.

The elevations are striking, and the design is in the Moorish style. The building consists of a central bay 344·4 feet long by 98·4 feet wide, covered by a single span roof of semi-circular section, 44 feet high at the springing, and 65·6 feet high at the crown. The roof is supported by lattice steel trusses, each truss made in two parts, pivoted at the ground level and at the crown; these support the iron roof structure, and there is a lantern at the ridge the full length of the bay. The trusses are spaced 34·4 feet apart.

Parallel to the central bay is the carriage bay, 204·5 feet long by 45·7 feet wide. At the end of the main bay is a transverse building which forms the front and faces the Conde de Xiquena

Street; this contains the waiting rooms, ticket offices, and other subsidiary departments.

The Author gives stress strain diagrams, and details of the calculations used in the determination of the roof design.

The building contract was let to Messrs. Carde and Escoriza, of Saragossa, and a large quantity of granite from Badajos has been used.

The steel constructional work was carried out by the firm Baume y Marpent.

The total cost of the building is not stated, but a detailed description with illustrations is given of the method used in the erection of the principal roof, and dimensioned plans drawn to scale of the structure are given.

E. R. D.

The Electric Working of the Swiss Main-Line Railways.

L. Thormann.

(Schweizerische Bauzeitung, 1901, p. 209.)

The Author remarks that the problem of working main-line railways by means of electricity, instead of by steam locomotives, has received a great amount of attention recently in most civilized countries, and the question is of specially great interest in Switzerland, as no other country is, in the opinion of the Author, so well adapted for electric traction.

The Author first gives examples of the great difficulty of dealing with the present traffic in which long trains are made up of parts going to various places, and thinks that short direct electric trains would give much better service. He considers that electric traction upon the main lines is already possible, and proceeds to compare the various systems of electric traction in order to select that which in his opinion is best for Switzerland. He wishes to make the existing water-power available and obviate the necessity for the purchase of foreign coal. He considers the use of batteries on trains impossible, and such locomotives as the Heilmann impracticable, as they consume coal. Three systems are discussed: (1) direct-current at 600 volts to 800 volts; (2) polyphase-current of 500 volts to 700 volts; and (3) polyphase-current of 3,000 volts to 10,000 volts; in all cases moving contact to be made with a conductor.

A list is given of railways upon which electric traction has been already adopted, specially alluding to the Berlin-Zossen and the Lecco-Sondrio (Italy) lines. The Author then considers the five principal lines in Switzerland, the Nord-Ost, Central, Gotthard, Jura-Simplon, and the United Swiss, and attempts to estimate the cost of electric traction and to compare it with the present cost of steam traction.

The total length of single track upon all the lines is 2,525 miles, and details are given of the gradients and of the total ton-mileage upon all these lines. The horse-power hours required per ton-mile is given as 0·043 as an average, and the consumption of coal per horse-power hour as 4 lbs.

Without attempting to offer a definite decision as to which is the best system the Author takes the direct-current with third-rail contact, and endeavours to estimate the approximate cost of the work if water-power were used. The current could be supplied to the contact rail at 1,000 volts and the return would be by the track rails.

The energy would be produced in the power-station as alternating-current and transformed into direct-current at sub-stations. After a long and detailed estimate the Author concludes that the total cost of the electric installation and rolling stock would be £6,440,000, and the annual saving by the use of electric traction in place of steam traction would be £177,504. The horse-power produced at the stations is estimated as 86,000.

E. R. D.

Microscopic Observations on Deterioration of Rails.

THOMAS ANDREWS, F.R.S., M. Inst. C.E.

(Engineering, 18 April, 1901, p. 501.)

This is an examination—chemical, physical, and microscopic—of a portion of an old Bessemer steel rail which had served for about 15 years on the main line of an English railway. The original weight of the new rail had been 82 lbs. per yard; its present weight was about 64$\frac{3}{4}$ lbs. per yard. The sides and bottom of the rail had suffered much from corrosion. It had also suffered from wear and mechanical abrasion near the chair-bearings to the extent of $\frac{1}{16}$ inch to $\frac{3}{16}$ inch in depth. The rail face was generally free from flaws. The corrosive deterioration near the chair-bearings was due to galvanic action when the rails and chairs were moist. In some places, where the rail had rested on the chairs, there was a transverse increase of width of $\frac{3}{16}$ inch.

The chemical analysis showed the combined carbon unusually low, silicon high, manganese very low, sulphur excessively high, phosphorus exceedingly high. It was only the low proportion of the carbon and manganese which had permitted this rail to wear so long without fracture.

The physical examination showed both strength and elongation to be inferior.

Numerous microscopical examinations were made of various parts, and it was found that local micro-segregation of the carbon and impurities had taken place in various places, and that there were many internal micro-flaws which might become dangerous.

The great loss of weight—about 1·15 lb. per yard per annum—the Author attributes partly to corrosive influences, but mainly to the abnormal excess of sulphur and phosphorus. The result points to the desirability of carefully watching the wear of rails, and of early removal of those which show signs of excessive deterioration, and the necessity of careful chemical analysis and physical tests of new rails.

The article is illustrated by three Tables and a number of drawings. C. H. M.

Braking Power for Trains. WEISS.

(Organ für die Fortschritte des Eisenbahnwesens, 1901, p. 214.)

The regulations agreed upon by the German Railway Union concerning the brake-power to be available on trains (engines and tenders excluded) have been undergoing reconsideration, and this Paper contains a discussion of the methods employed to arrive at a proper rule. The following formula was made use of for first-class railways of heavy construction :

$$B = \frac{1\cdot25}{f_1}\left(\frac{0\cdot42\, v^2_1}{550 + 2v_1} - 0\cdot1w_1 + 0\cdot1a\right)$$

In this formula B indicates the percentage weight of the train, excluding engine and tender, which is borne upon braked wheels ; v is the speed in kilometres per hour; v_1 is equal to $v + 0\cdot5a$, a being the fall per thousand ; f_1 is the mean coefficient of friction between wheel and brake-block, the initial speed being v_1 ; w_1 is the mean value of the rolling resistance in kilograms per ton.

A different formula was used for light railways, as the level crossings are not watched, thus requiring trains to draw up in less distance, while the speeds are of course less than on heavy railways.

The value of f_1 is obtained from a special formula of considerable

Speed in kilometres per hour		20·0	40·0	60·0	80·0	100·0
Speed in miles per hour . .		12·4	24·8	37·3	49·7	62·1
Fall per Thousand.	Gradient.	Percentage of Weight on Brake-wheels.				
1	1 in 1,000	6	9	23	44	72
10	1 in 100	10	21	38	62	91
20	1 in 50	21	35	56	82	
30	1 in 33·3	33	51	74		
40	1 in 25	47	68			

length. The resistance of the train (wagons and carriages only) was calculated from the formula:

$$w_1 = 2 \cdot 4 + \frac{v^2}{2,600}$$

The Table at p. 376 is made up from values taken from the extended Table given in the Paper as for heavy railways.

The gradient in this Table is the steepest average gradient for a length of 1,000 metres (5 furlongs) on the line in question.

J. G.

The Mechanical Handling of Luggage. A. DA CUNHA.

(La Nature, 11 January, 1902, p. 87.)

At the new station in Paris of the Orleans Railway Company, a system has been introduced for the handling of passengers' luggage which presents many novel features. The station is on two different levels, the ground floor being reserved for the offices and the arrival and departure of passengers, and the basement contains the platforms and the lines of rail. The difference in level between them is 19·68 feet, and, allowing for the height of the platform above the rails, an actual difference of 16·95 feet. It was simple enough to devise a means of lowering the luggage to the departure platform level by lifts, but the problem was to convey the luggage from the arrival platforms to the upper level and to sort it, so that each passenger could readily find what belonged to him on reaching the street level. By means of electrically-driven travelling-belts in constant motion, it is found possible to arrange that, as fast as the luggage is removed from the vans, it is conveyed by the porters to special shoots leading to the travelling-belts. From these it descends at first to a subway placed below the platform, and then on reaching the extremity it rises, by an inclined lift, to a height of 6 feet 6 inches above the distributing counters on the upper floor. All the luggage from the vans in any part of the train is conveyed by the travelling-belt to one spot where there is a right and left shifting platform, on which the officials can readily sort the numbers over or under five on the labels, with which every package is furnished. Passengers whose luggage-checks end in numbers from 1 to 5, find their boxes on one counter, and the numbers from 6 to 0 are arranged on the other counter. Illustrations are given of the details of this system, which the Author states involves the attendance of a considerable number of porters and workpeople, and would only be suitable for large and important stations with very considerable traffic.

G. R. R.

Electric Traction on Main Lines. E. Huber.

(Engineering, 11 April, 1902, p. 481.)

This is an article dealing chiefly with a Paper read before the Zürich Association of Engineers and Architects on 27th February last. The Author set forth the advantages to be gained by the Ward-Leonard system, and gave some particulars of the work already accomplished by the Maschinen Fabrik Oerlikon in elaborating a complete scheme of heavy electric traction on these lines. He proposes to use a trolley line conveying to the locomotive an alternating current at a potential of about 15,000 volts. By means of a motor-generator on the locomotive, this current is used to generate a continuous current at 700 volts, which, in its turn, is used to drive the axle motors. By altering the excitation of the fields of these motors, and of the continuous-current generators, the speed of the locomotive can be varied in a practically continuous fashion without wasting current in external resistances. Mr. Huber holds that a locomotive should be able to take a train of 250 tons up a gradient of 1 in 100 at 25 miles per hour; to do which, he estimates 575 HP. is necessary at the drawbar. Such a locomotive is now being completed by the Oerlikon Company. Its weight, in working order, is 44 tons. This engine is compared with a three-phase locomotive of equal power, weighing only about 30 tons. The Author admits that a trolley-wire at 15,000 volts is probibited in most cases by Government regulations; but he does not despair of having the law altered. The scheme is then examined in some detail. For the safe employment of such high-tension currents the Oerlikon Company have worked out an entirely new arrangement of trolley-wire suspension and current collection. In addition to the great facility with which speed and power can be regulated with such a locomotive, another advantage is the ease with which power can be returned to the line on descending grades, or in stopping at stations, or the like.

C. H. M.

Rigidly Fixed Longitudinal Sleepers on Railway Bridges.

T. van Hettinga Tromp.

(De Ingenieur, 1901, p. 793.)

During a discussion at the Koninklijk Instituut van Ingenieurs on defects observed in longitudinal sleepers on railway bridges, Mr. N. C. Kist mentioned the different ways in which these were fixed to the other parts, and thereby came to the following conclusions:

1. That the defects were due to the rigid fixing to the cross beams.

2. That sleepers laid free in their supports, only fastened by bolts and nuts, worked loose and rusted in the joints.

3. But that the fixing of the longitudinal girders to the cross beams with short angle bars could be recommended, on condition that only the web plates of the beams were connected, and the flanges left free.

The Author has investigated these points practically and theoretically, and concludes from this that really rigid fixing is unattainable. Either bolts or rivets work loose, angles get torn or cracked, and therefore the system devised does not give the security against accidents which at first sight it might promise. To the Paper are added several drawings.

H. S.

The Stiffening System of Long Span Suspension Bridges for Railway Trains. J. Mayer.

(Proceedings of the American Society of Civil Engineers, February, 1902, p. 111.)

The Author in this Paper considers the preliminary calculations necessary for the design of a railway suspension bridge of 2,800 feet span, to carry a moving load of 8,500 lbs. per linear foot; he estimates the dead load at 28,000 lbs. per linear foot. For a bridge of this size, the dip of the cables of the main span being one-eighth of the span, the Author calculates that the drop of the cables at the centre of the span due to a rise of temperature of 120° is equal to 7·4 feet; and for the given load, taking a unit stress in the cables of 70,000 lbs. per square inch, he makes the variation in height at the centre due to elastic strain as 6·4 feet. He investigates the difference in economy between employing two-hinge or three-hinge stiffening trusses, and finds that the former adds 28 per cent. to the total load of the main span compared with the latter. He then calculates the difference in cost between stiffening trusses and braced chains, and shows that the former are considerably more economical in the case under consideration. He proceeds to estimate the stresses from moving loads in three-hinged stiffening trusses,—by finding which positions of the moving loads give the greatest bending moments and shearing forces; assuming, in the first place, that the curve of the cable remains under all circumstances a parabola, and afterwards investigating the diminution of the stresses due to the deformation of the stiffening trusses. Finally, he considers the proper unit stresses in the stiffening trusses for a bridge of the given dimensions.

A. W. B.

The Condition of the Brooklyn Bridge.

BUCK and LA CHICOTTE.

(The Railroad Gazette, 10 January, 1902, p. 20.)

This is a special report in the Annual Report of the Commissioner of Bridges, dealing with the report on the same bridge by Messrs. Duryea and Mayer.

Though there is some warrant for the damaging criticisms of Messrs. Duryea and Mayer, yet they fail to show where the defects indicated have produced serious results.

There is a good deal of assumption and hasty preparation on insufficient data. The erroneous nature of some of the conclusions and premises on which they are based is shown. The computations given in that report are crude and difficult to follow. There is much discussion of conditions wholly foreign to those existing in the bridge, and the use of formulas containing conflicting and confusing nomenclature. There seems to have been no use made of Colonel Washington Roebling's report of 1st January, 1877, and other essential data, containing the assumption on which the original design was based.

The computations concerning the points wherein the safety of the structure is concerned materially in question are then dealt with. They may be divided under four heads: (1) stresses in the lower masonry; (2) bending stresses in the cables at the centre of the main span; (3) excessive stresses in part of the floor system; (4) excessive executive stresses in bottom chords due to stay connections and excessive stresses in these connections themselves.

These points are all gone into in considerable detail, showing that Messrs. Duryea and Mayer's views and conclusions are incorrect. They then summarise their conclusions. There is warrant for finding fault with the methods of maintenance and inspection. Wind had little to do with the accident. It was caused mainly by longitudinal movement of the trusses under temperature changes and moving load. The stresses in the floor system are higher than should be permitted in some parts. The bending stresses in the cables at the centre of the bridge are not material. The attachment of the overfloor stays to the bottom chord, and the bent stirrup rods is not good, but the defect is not serious. The general scheme of reconstruction is very questionable. Although a full report as to conditions of loads and stresses cannot be made until the results of the survey of the bridge are obtained, nor detailed recommendations made as to what should be done, they think general recommendations can properly be made here, which they do accordingly. They believe if these suggestions are acted upon the bridge will be put and maintained in such condition that it will serve in perfect safety for an indefinite term of years.

C. H. M.

The Triangulation for a Bridge across the East River, New York. O. Erlandsen.

(Engineering News, vol. xlvii., 1902, p. 126.)

Surveys for the bridge over the East River between the boroughs of Manhattan and Queens were begun early in 1900. This bridge will consist of a cantilever span of 1,131 feet over the west channel, a cantilever span of 984 feet over the east channel, a fixed span of 630 feet over Blackwell's Island, an anchor span of 469·5 feet in Manhattan, and an anchor span of 459 feet on the Queens side, making a total length of 3,673·5 feet. The distances across both channels were obtained by triangulation, and it was found necessary to make the base line and the check base on Blackwell's Island form part of the same straight line. They were measured with a long steel tape supported at regular intervals of 25 feet, the tape being $\frac{1}{8}$ inch wide and 200 feet long. The points of support were not level, and there was not a continuous inclination for the entire length of the line. Moreover, the points of supports were only temporary, and were set up anew for each measurement. The intermediate supports consisted of wooden rods, 1 inch thick and 2 inches wide, shod with steel points and held vertical by means of a special extension leg tripod. To each end of the tape was attached a piece of light brass chain that passed over the adjustable end support to a pin driven into the ground. The end of each measurement was marked on an adjustable table. Its top was a steel plate 6 inches square, on which was pasted a sheet of paper on which the end of the measurement was marked with a sharp pencil. The base line and check base were measured four times, the results corrected for inclination and temperature being 1,671·030 feet, 1,671·028 feet, 1,671·028 feet, and 1,671·060 feet for the total length of the two bases. The fourth result was discarded owing to the prevalence of high winds. The average was assumed to be 1,671·03 feet, of which the base line was 1,122·05 and the check base 548·98 feet. The angles were measured with an 8-inch transit theodolite reading to 10 seconds. There were four triangles in all, one on the base line for each channel and one on the check base for each channel. The distances across the west and east channels were found to be 1,401·793 feet and 1,258·033 feet respectively. The base of verification was calculated to be 548·977 feet and 548·991 feet, the measured length being 548·980 feet. The special apparatus employed in the survey was devised by Mr. R. R. Crowell, under whose direction the work was carried out.

B. H. B.

A Concrete and Steel Bridge over the River Caudal in Spain.

GABRIEL REBOLLO.

(Revista de Obras Públicas, 1901, p. 197.)

The Hennebique system of concrete and steel construction has been largely used in Spain, and the Author gives details of its adoption in a bridge recently built over the River Caudal in Mieres. The bridge was designed by Mr. Ribera, and consists of two arches, each 175·5 feet span, with a rise of 19·6 feet and 22·3 feet respectively. The pier is also of steel and concrete, and the abutments of masonry, the total width of the bridge being 26·24 feet. The thickness of the arches which support the floor of the bridge is 1·64 foot at the crown and 2·62 feet at the haunches; their width is 1·31 foot. The Author then compares the dimensions of this bridge with those which would be required if a similar bridge had been built of hewn stone, and concludes that, while the approximate weight of the Hennebique structure is 326·6 tons, that of the stone bridge would have been 1,650 tons, the volumes of the two structures are as 1 : 5·25, and the prices per unit are as 3 : 1; therefore not only is the Hennebique structure much more elegant from its lightness, but a notable saving in cost is obtained. The load upon the abutments being far less, the masonry may be much smaller. Leaving the pier out of the calculation, there were 4,000 cubic feet of concrete and 504 lbs. of steel per lineal foot of the bridge, and the price would be on the average 3*s.* 8*d.* per cubic foot of steel and concrete erected on the site; this is equivalent to about £15 per lineal foot of the bridge. It appears, however, that these are only approximate figures, as the Author was not aware of the exact costs, which were not kept separate from the costs of the rest of the work. Calculations for loading follow, and details of the sections of steel employed.

E. R. D.

Theory of Masonry Arches. TH. LANDSBERG.

(Zeitschrift des Vereines deutscher Ingenieure, 1901, p. 1765.)

Although the experiments carried out by the Austrian Society of Engineers and Architects proved that masonry arches may be regarded and calculated as elastic arches, the application of the theory of elasticity in the design of arched bridges has not become at all general. The reason for this is probably that the calculations required have been wanting in simplicity, and the Author proposes to show how the methods may be simplified. The arch is supposed to be fixed at both ends and is thus a threefold statically indeterminate structure. If a single load act at any point it transmits the force to the abutments through two straight lines—the lines of the abutment reactions. The locus of the

intersection of these two lines as the load moves across the bridge is called the reaction curve. The lines of the two abutment reactions form the envelope of a curve, which may be called the reaction envelope. It is the construction of this curve which seems to have formed the chief obstacle to the application of the elastic theory, and the Author discards its use altogether. For the application of the Author's method the centre line of the arch is assumed to be a flat parabola, and in this case the reaction curve becomes a straight horizontal line at a height above the apex equal to one-fifth the rise of the arch. The next step is to draw a line parallel to the reaction line at a height above the abutments equal to two-thirds the rise of the arch. Let the points where this line cuts the vertical lines of the abutments be called A, B. Then, supposing the load at a point distant x from the centre of the span, calculate the values of the following expressions:—

$$v = \frac{8}{15} f \left(\frac{l}{l + 2x} \right)$$

$$v' = \frac{8}{15} f \left(\frac{l}{l - 2x} \right)$$

Drawing v and v' downwards from A and B fixes points A′ and B′ through which the abutment reactions pass. The other point is fixed by the reaction line. The Author shows how his method is utilized to deal with the dead and live loads. He also gives an analytical solution of the problem.

J. G.

The Supporting Power of Piles. E. P. Goodrich, Jun. Amer. Soc. C.E.

(Proceedings of the American Society of Civil Engineers, December, 1901, p. 1095.)

The Author develops a general formula for the bearing power of piles and compares it with numerous existing formulas. He also describes an apparatus for showing the exact amount of vertical motion of a pile at each instant of its movement during a blow. This consisted of a frame which could be held near the pile by arms resting against the guides in which the hammer of the pile-driver moved. A piece of smoked glass about 8 inches by 6 inches was supported at the corners by four vertical indiarubber bands, attached to four pegs on the frame, so that the glass could move horizontally. At one side was a catch to stop and hold the glass at the end of a single vibration, and at the opposite end a trigger holding the glass, which, when released by the fall of the hammer, allowed it to make a single vibration. Time was marked on the smoked glass by a wire fastened to one prong of a tuning-fork, whose prongs were pressed together by a strip of metal attached to the frame, so that they were released when the glass

commenced its vibration. A wire projecting from the hammer traced a line on the smoked glass as the hammer fell. From the results it appeared that the law of variation of the velocity is such that the penetration, measured from the deepest point, varies as the square of the time measured from the final instant. Finally, the Author recommends that piles shall be driven to such depths that the last blow of a 3,000-lb. hammer, falling freely 15 feet, shall not produce a penetration greater than 1 inch or an equivalent penetration directly proportional to the weight of the hammer. A. W. B.

The Construction Works on the Simplon Tunnel.

S. Pestalozzi.

(Schweizerische Bauzeitung, 1901, p. 191 *et seq.* Fifty Figs.)

The Author points out that a full description of the original scheme for the tunnel, abstracts from the chief reports and also from the quarterly reports of progress have already appeared in the *Schweizerische Bauzeitung*, but as yet no account has appeared of the stations outside the tunnel for producing the necessary power for its construction, nor has a description of the special tools yet been given.

At the north end of the tunnel the necessary power is obtained from the Rhone. The point at which the water is taken off is about 2·48 miles above the end of the tunnel and at a height of 2,424 feet above sea-level. The water passes thence by an open canal to a storage reservoir, from which it descends through a pipe under pressure for a distance of 1,632 yards to the turbines, the total fall being 171 feet. With the maximum flow 2,230 HP. is produced, but only about 1,470 HP. was employed at first. The Author then describes the weir on the Rhone in detail, and the means taken to prevent ice and gravel passing into the canal. The latter is 3,488 yards long, and the raised portion was originally intended to be made of wood, but it has actually been built in concrete and steel on the Hennebique system, and fully dimensioned drawings are given in the original; the structure has an internal cross section 6·23 feet by 6·23 feet. In this manner the canal is carried over a main road and also across valleys. The pressure pipe is constructed of wrought iron, and is 5·25 feet in diameter. It is carried over the Rhone upon a specially constructed wooden bridge.

The Author then gives a long and detailed description of the works at the south end of the tunnel, which are of a very similar character to those already described. The water is obtained from the River Diveria.

At the north end there is a flat expanse of land, 1·24 mile long by 109 yards to 163 yards wide, which affords ample room for the plant. The Author gives a detailed description of all the plant, the various buildings, locomotive sheds at each end of

the tunnel, and also alludes to the special machinery used in the work. The description extends through a large number of the issues of the journal, and is profusely illustrated by photographs, drawings and maps.

E. R. D.

Comparative Tests of Roof-Trusses. A. BAUDOUIN.

(Mittheilungen des K. K. technologischen Gewerbe-Museums in Wien, 1901, p. 191.)

The Author states that part of the professional course in carpentry at the Institution, lasting 12 weeks, was devoted to the construction, by the students, of two full-size roofs differing entirely in design; these roofs were afterwards tested to the breaking-point, and valuable facts were obtained concerning their relative merits and defects. In each case the area roofed over was 53·3 feet in length by 33·7 feet in width, the clear span being 30·7 feet. The pitch of the roof was the lowest permissible for slating—namely, 26°. The first truss was somewhat in the nature of a queen-post truss, and in the other the principal was in the form of a segment arch, the arched rib being constructed of three thicknesses of 2-inch boards, 8¼ inches in width, bolted together. The principals were in both roofs 13·1 feet from centre to centre, and the rafters were 3·28 feet from centre to centre. All the details of construction are fully indicated in the accompanying drawings, together with the dimensions of the timbers. Each roof was tested by loading with pig-iron. It was estimated that every square metre measured horizontally would have to bear about 200 kilograms (90 kilograms for timber and slates, 75 kilograms for 2 feet of snow, and 30 kilograms for wind pressure), equivalent to about 41 lbs. per square foot. The load was also placed proportionately, first on the right slope of the roof and then on the left, to represent the unequal loading due to the approximate weight of snow and the wind pressure. The factor of safety was assumed at one-sixth of the actual breaking weight. Full particulars are given of the tests and of the manner in which each form of truss yielded. The queen-post construction gave rather more favourable results than did the arched rib.

G. R. R.

Traction on Wagon Roads. IRA O. BAKER.

(Engineering News, 6 March, 1902, p. 182.)

The Author recently made some experiments on different roads and pavements. Resistance to traction consists of axle friction, rolling resistance and grade resistance. The latter need not be further mentioned here. Axle friction varies from 0·012 to 0·02 of the load, with good lubrication—like journal friction in machines.

Defective lubrication increases it very much. Tractive power to overcome axle friction for ordinary American carriages is 3 lbs. to 3½ lbs. per ton, and for wagons with medium-sized wheels and axles 3½ lbs. to 4½ lbs. per ton.

Rolling resistance varies (1) inversely as some function of the diameter of the wheels. Table I shows results (hitherto unpublished) obtained by Mr. T. J. Mairs, at the Missouri Agricultural Experiment Station, with different-sized wheels. The tractive force per ton was—with wheels 50 inches, 38 inches, and 26 inches in diameter:—

	Lbs.	Lbs.	Lbs.
On a macadam road	57	61	70
„ Timothy and bluegrass sod, dry, grass cut	132	145	179
„ „ „ „ „ wet and spongy	173	203	288
„ ploughed ground, not harrowed, dry, cloddy	252	303	374

(2) with the width of the tire. Table II shows results of an elaborate series of experiments by the Missouri Agricultural Experiment Station, showing that on poor macadam, poor gravel and compressible earth roads and on agricultural lands the narrow gauge gives less traction, with certain exceptions which are specified. On earth road, loam, dry, with loose dust 2 inches to 3 inches deep, traction with 1½-inch tire was 90 lbs., and with 6-inch tire 106 lbs.; on same road, but dry, hard, no dust, no ruts, it was 149 lbs. with 1½-inch tire and 109 lbs. with 6-inch tire. On broken stone road, hard, smooth, and no dust or loose stones, it was 121 lbs. with 1½-inch tire, and 98 lbs. with 6-inch tire. Table III gives data on the effect of width of tire upon tractive force obtained by the Studebaker Bros. Manufacturing Company, South Bend, Indiana, in 1892, with an ordinary 3½-inch thimble-skein wagon (3) with the speed. On a good broken stone road the traction at walking pace is 42 lbs., at ordinary trot 49 lbs., and at a fast trot 50 lbs. per ton. Moisture of surface and mud increase the traction. Table IV is a summary of Morin's results. With 44-inch front and 54-inch back wheels, on a hard and dry road, the traction was 114 lbs. per ton with either 1¾-inch or 3-inch tires, whilst on wood block pavement the traction was 28 lbs. per ton with 1¾-inch tires and 38 lbs. with 3-inch tires—(4) with springs. The effect of springs is to reduce traction—more so at high than at low speeds. Apparently no experiments have been made on the effect of springs—(5) with different road surfaces. Table V is a summary of Morin's results for the traction of different vehicles on various road surfaces. On a good broken stone road in good condition, with or without springs, the traction varies from 24 lbs. to 42 lbs. per ton at a speed of 3 miles per hour. Table VI shows data obtained by the Author. The tractive power was determined by a Baldwin dinagraph, which is illustrated by two figures. The road surfaces tried were, asphalt, bricks, granite, macadam and steel wheelway. The traction varied from 17 lbs. to 70 lbs. per ton, the average being 38 lbs. per ton.

H. M.

The Alterations in River-channels and Beds near the crossing of Railway Bridges. A. B. MARINKELLE.

(De Ingenieur, 1901, p. 607.)

The works in connection with the construction of railway bridges across the wide rivers of the Netherlands, often include widening, or restricting, the cross-section of the stream near the site, as also above and below it, to compensate for the obstruction caused by piers and approaches. The object to be held in view is to accommodate the clear openings to the requirements of the river discharge in different states, so as to obtain the least possible disturbance in the currents and surface gradients. Should the opening be too small, causing a diminished surface gradient above the obstruction, the current through the clear will inconveniently increase. On the other hand, if the widening at or near the spot be in excess, there is danger of silting-up occurring in undesirable places, and troublesome changes in the river-bed below. In each case the subject must be carefully considered. As an instance of the preliminary investigations in this direction, that with regard to the railway bridge at Buggenum, near Roermond, is given. The line crosses at a double bend in the River Maas, where the permanent deep or summer channel lies between extended foreshores, submerged during floods. The total width from bank to bank is about 5,330 feet, of which the deep channel occupies about 330 feet. The cross-sectional area is about 1,450 square metres (14,500 square feet) and during floods 2,200 cubic metres (77,700 cubic feet) passes per second. During an exceptional flood this volume reached 2,600 cubic metres (92,000 cubic feet) per second. In floods only part of the total flows down the deeper channel and the rest over the shallower foreshores at a diminished velocity. It would have been extravagant to provide for the whole of this last volume by open viaducts in the long approaches, instead of using the cheaper embankments. The question was to determine the probable effect of such an obstruction and the size of openings required in the principal work, so as to avoid an increased current between piers and abutments, and prevent diminished velocities leading to changes in the river-bed in the lower reaches. The observations and calculations based thereon are fully given and made clearer by a situation-plan and sections added. H. S.

The Canal Lock of the City of Utrecht at Vreeswijk.

G. G. CALKOEN.

(De Ingenieur, 1901, p. 197.)

In 1373 the citizens and guilds of Utrecht built, at their own expense, a lock in the river dam of the Leck at Vreeswijk to insure a better communication by water with the Rhine for their

commerce with Germany. Probably this lock was of the then usual pattern; a door sliding up and down between vertical guide posts and raised by a windlass overhead. At least in old records the act of opening the lock is called "winding." The opening was only 12 feet in the clear, broader ships had to trans-ship their cargoes outside into smaller craft. This first lock, entirely of timber, like several subsequent structures, not only served the purposes of navigation, but also for letting in Rhine water for the use of the inhabitants of Utrecht, and surrounding country, in times of drought. Ever since the first work came into existence, renewals, repairs, widening and alterations had to be undertaken, often caused by changes in the river-bed and the silting up of its northern foreshore. In 1652 the lock was widened to 19 feet, and provided with double pivoting doors and a swing-bridge, to allow ships passing through with masts standing. In 1741 and 1822 the lock was again widened to 22 feet and 25 feet respectively. During the whole of this period the works were paid for and belonged to the town of Utrecht, and ever managed to the public interest in the most generous spirit. It is therefore considered a great hardship that the Public Works department should now claim to bring them under the sole administration of the department, through which it is feared that local interests will suffer most seriously.

H. S.

The Repair of the Locks at the Mouth of the Walcheren Canal. T. G. Ermerins.

(De Ingenieur, 1902, p. 54.)

In the interest of the sea-going navigation between Middelburg on Walcheren and the Zeeland estuaries, new locks were built in 1868 at the entrance of the harbour canal at Veere. The work consisted of two locks, one, 20 metres wide in the clear (66 feet 8 inches), 146·80 metres long (489 feet 4 inches), depth of sill below N.A.P. (mean high water at Amsterdam) of 6·55 metres (21 feet 8 inches), and a smaller lock contiguous, width 8 metres (26 feet 8 inches), length 64·40 metres (214 feet 8 inches), depth of sill 4·05 metres (13 feet 2 inches). Both locks were constructed as one work, resting on a pile foundation, filled in where required up to the flooring with sand and concrete. The subsoil at the spot was hard sand, through which it was difficult to drive the piles—sinking by means of a water-jet not being in use at the time. In 1873 symptoms of leakage were observed, and it was found that with varying in- and outside water-levels, a flow passed through the foundations, carrying with it considerable quantities of sand, which subsided on the lock floor. To remedy this, double rows of sheet-piling were driven, surrounding the whole work, without very favourable results. In 1895, after continual trouble,

further investigation showed as a cause the subsidence of the sand underneath the floors and stringers, which had been disturbed by the pile-driving, thus leaving spaces for the infiltration of water. The pile-heads, stringers, cap-pieces, and, in some parts, the flooring, were attacked by *teredo navalis*, endangering the stability of the walls. After several experiments, the forcing in, under pressure, of Portland cement grout into the spaces made by subsidence and scouring succeeded. An additional row of sheet-piling was driven in front of the entrance. Until the present time no further leakage has been noticed. While this was going on, the deep-water lines in the estuary, the Veersche Gat, gradually receded to the northward away from the locks. In 1865 the entrance was already separated from the main channel by a bank, on which still 26 feet were sounded, but this subsequently shallowed to such an extent that even steamers drawing 10 feet to 12 feet could only reach the entrance by a very circuitous route. Many proposals have been made lately with a view of restoring the ancient conditions by means of a groyne or similar work projecting from the north shore of the pass, so as to force the currents on to the shore near Veere. The large expenditure which such work would require is the reason that, for the present, relief is sought in dredging operations. The usual internal passenger steamers are no longer delayed, but sea-going vessels no longer use this route, and go round by Flushing.

To the Paper are added several drawings and charts.

H. S.

The Widening of the Wilhelmina Quay at Rotterdam.

WONTER COOL.

(De Ingenieur, 1902, p. 127.)

The increasing draught of the steamers frequenting the port of Rotterdam made it desirable to provide greater depths alongside of the Wilhelmina Quay. Dredging in this spot on a sloping bottom would have undermined the existing work and brought it down. So it was decided to widen the wharf by 15 feet, and bring the quay face forward into deeper water. Six rows of piles were driven parallel to the old work, carrying a heavy timber flooring on stringers and cap-pieces at the level of low water. On this platform transverse concrete walls were built 1 metre (3·28 feet) thick, and 3 metres (10 feet) apart, leaving chambers 2 metres (6·56 feet) wide, open at the front. These spaces were then covered in with slabs of armed concrete, 16 feet 6 inches by 9 feet surface, and from 7 inches to 9 inches thick. The iron rods imbedded in the concrete were of $\frac{1}{4}$ inch to $\frac{3}{8}$ diameter, and the concrete 1 cement to 4 ballast. The slabs withstood a test load of 7 tons per square metre equally distributed, this being greatly in excess of any weights to be carried when placed. The

concrete work was then covered in with a layer of 2 feet of sand and the usual paving. The depths along the widening are now 23 feet and over at low water.

H. S.

Dredgers. C. H. Holst.

(De Ingenieur, 1901, p. 778.)

The earliest recorded arrangement for deepening canals mechanically is that of the "Mudmill," on the Great North Holland navigation canal, between Amsterdam and Helder, constructed in the beginning of the Nineteenth Century for the use of sea-going vessels. The depth required was too great for the usual hand-dredging with bag and spoon. In this first dredger no buckets were used, but a rectangular channel went down from the deck of the punt to the canal bottom, at an acute angle. The lower end was armed with an iron shoe, and rammed forward into the mud, and this brought up by vertical paddles on an endless band, through the gutter to the deck, from which it was shovelled over into scows alongside. The gearing was driven by a horsemill with eight or ten horses. About 400 cubic metres (500 cubic yards) could in this way be excavated per day, but only in long parallel furrows, no side action being possible. The next engine was built for the town canals of Amsterdam, driven by steam, and here buckets on a vertical ladder were introduced, making a lateral or sweeping action feasible. After this, improvements in appliances and construction rapidly followed each other, so that at present dredgers, some of large dimensions, are used for many different purposes, in excavating soft mud and silt, harder material, even rocks or sand by suction, in gold placer mines or in peat fens for the preparation of fuel. The different types are described and illustrated by many sketches.

H. S.

The West Pass of Soerabaya, and Communication between Holland and Java. W. F. Leemans.

(De Ingenieur, 1901, pp. 809.)

Notwithstanding the diversion of the Solo river mouth to a point away from the Straits of Madura and the roadstead of Soerabaya, the West pass soundings show continual diminution in depth. Even now steamers of 5,000 or 6,000 tons cannot reach the roadstead with unbroken cargoes. As the draught of ships is steadily growing, the shallowing observed in late years will fatally cut off the important port of Soerabaya from ocean traffic, unless the danger is seriously combated, and a remedy provided. The sea bottom of the straits between Java and Madura consists of

about 20 feet of soft silt, displaced by even slight currents. The flood tide coming up from the eastward passes the narrows and then deposits enormous volumes of silt in the widening parts of the West pass. It is proposed to restrict this fan-shaped expanse by constructing a dam from the Java shore, running about N.N.W. from Fort Erfprins, parallel to the Madura coast. This would leave a channel 4 miles wide, which would lead the current into the deep waters of the Java sea. This dam will have to be of a total length of 12 miles and laid over soft mud. Its specific gravity must not exceed 1·35 that of the local mud, so as to avoid settling down into the silt. The use of caissons built up of iron enclosed, or armed concrete, is indicated, as in this way cross sections may be obtained which will more or less float in the mud, and at all events compress instead of deplacing it sideways, forming in this way more compact layers. The dam will also more efficiently exclude from the fairway the deposit from the Solo river, which has still a tendency at certain times to fill up the West pass. Unless something in this direction is done the evil will be aggravated, and the most important port of Java become useless. On the other hand, the proposed work will insure a permanent channel, with minimum depths of 26 feet, admitting the largest ocean steamers of the present time.

H. S.

The Application of Lauterburg's Formula in Determining the Discharge of Rivers in Java. A. P. Melchior.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1901–1902, p. 46.)

Notwithstanding the most careful investigation and inquiry as to the maximum discharge of rivers in a country lacking systematic series of observations on rainfall extending over long periods, it happens that floods occur, reaching greater levels and volumes than were remembered by the oldest inhabitant. Repeatedly bridges, drainage channels, and similar works proved inadequate shortly after completion, although it was supposed, from trustworthy information, that large margins of safety had been provided. The want was felt of a more scientific method of fixing this limit of safety in cases where the authentic records did not go back far enough. Lauterburg's formula, based on observations in Switzerland, seem to indicate a way to obtain reasonably trustworthy estimates. They have to be altered to suit the atmospheric and local conditions to be of use in Java. In these formulas the coefficients are: the extent of the river valley, the vertical configuration, the nature of the soil and of the vegetation. Unaltered coefficients given by Lauterburg were found to give results too low for conditions reigning in Java, with its tropical rainfall, and alternating wet and dry seasons. The rainfall in different parts of the same river basin is often very dissimilar, and, to obtain some sort of averages, these basins were

divided up into triangles by uniting in threes by straight lines such spots on the map from where rainfall records were obtainable. The mean rainfall was then considered to be the average of recorded rainfall in the angles.

On the whole the results were satisfactory, and, for more extended use, Tables and diagrams were composed which are added to the Paper.

H. S.

[NOTE.—From data collected in Switzerland, Lauterburg endeavoured to obtain formulas useful in framing rational estimates as to the probable discharge of rivers. He observed that the amount of rainfall often varied considerably in different parts of the same river-basin if this were of any extent, and that the length of time between the moment of rainfall, and that of the consequent rise of the water-level in the river, was influenced by the topographical and geological features of the soil and the nature of the vegetation. For the average discharge per second of a river he gives the formula—

$$\phi = \frac{1{,}000{,}000}{31{,}530{,}000}\, \mathrm{C}\, h\, \mathrm{F} = 0 \cdot 03171\, \mathrm{C}\, h\, \mathrm{F},$$

in which ϕ = average quantity per second,
F = area in square kilometres,
h = total yearly rainfall in metres.

C a coefficient determined from local circumstances, which for marshy soil is taken at 0·2; for level plains, 0·25; rolling ground, 0·30; low hills, 0·35; hilly country like the Ardennes, the Odenwald, the Eifel, at 0·45; the Black Forest, the Vosges, 0·55, and, for high rocky mountains, at 0·70. With the necessary modifications similar formulas may be employed for estimating the discharge for periods shorter than a year, and separate indications obtained for dry or rainy seasons, or for floods or spates after exceptionally heavy rainfalls. The information obtained may be useful in questions of water-supply, for instance, or for irrigation or motive forces, or for determining the clear openings in bridges, or the dimensions of embankments confining a river-channel.]

Lauterburg, Schweizerische, Stromabflussingen. Bern: Huber & Co., 1876, Allgemeine Bauzeitung, 1887. Heft 3–5 and 12.

H. S.

The Cooling of Enclosed Spaces. Dr. G. RECKNAGEL.

(Zeitschrift des Vereines deutscher Ingenieure, 1901, p. 1801.)

The aim of a complete theory of heating is to express the relations between the heat supplied to the enclosed space, the thermal properties of this space and its surroundings, and the time. The solution of this problem must be preceded, however, by a theory of cooling which will determine the temperature of the internal walls and atmosphere of a room as a function of the time, the room being supposed left to itself and not supplied with heat. It is this process of cooling to which the Author directs his attention. It is assumed that the space has no doors or windows, and that only one side is composed of heat-conducting material. If the state of temperatures is steady the theory is fairly simple, the flow of heat through the wall is then simply proportional to the thermal conductivity λ, and to the temperature gradient across the wall, which is equal to $\frac{(\mathrm{T}_i - \mathrm{T}_o)}{\delta}$, T_i and T_o being the temperatures of the inner and outer surfaces of the wall

and δ its thickness. For rubble walls the Author puts λ at 0·7, that is the amount of heat (number of calories) passing through 1 square metre of the wall per hour for a temperature gradient, the tangent of which is unity (5·2 for units, foot, hour, degrees Fahrenheit and British thermal units).

Putting J for the temperature of the atmosphere in the room, A for the outside temperature, the Author obtains a value for p (called the coefficient of transmission) by which to multiply the difference between J and A in order to find out the heat lost through 1 square metre of the wall per hour. The value of p is obtained from the equation

$$\frac{1}{h_1} + \frac{\delta}{\lambda} + \frac{1}{h_2} = \frac{1}{p},$$

h_1 denoting the number of calories taken up by 1 square metre of the inner face of the wall per hour when the temperature of this face is 1 degree below the temperature of the room; h_2 is the corresponding coefficient for the heat given off from the outer face of the wall under corresponding conditions. As to the values of h_1 and h_2, under the conditions normally assumed in heating problems, and taking the internal and external temperatures to be 20° C. above and below zero respectively, the Author puts h_1 at 6, and says that h_2 may vary from 6 to 36, according to the wind. The Author then enters fully into the discussion of the case when the temperature of each layer of the conducting-wall varies with the time, and the temperature of the enclosed space falls. He gives the complete derivation of the differential equation connecting the temperature with the time, and in the solution of this equation introduces an additional constant to those usually taken. The determination of the values of these constants forms a large part of the Paper, and the final formulas are applied to numerical examples. Assuming that a room, having attained a steady state of temperatures of the degrees mentioned above as being usually assumed, has the supply of heat cut off, it appears that the temperature of the inner face of the wall falls very rapidly compared with that of the outer wall, and that the line of temperature gradients through the wall, from being straight, becomes sharply bent near the inner face, afterwards flattening out, until finally the temperatures become everywhere the same as that of the outer atmosphere.

J. G.

Notes on the Construction and Operation of Cooling Towers.

J. R. Bibbins.

(Engineering News, 20 March, 1902, p. 223.)

In view of the comparative absence of reliable data on the operation of cooling towers in general, the following notes are ubmitted, including the description and tests of an experimental

tower recently put into service by the Edison Illuminating Company of Detroit. Deductions are drawn from the tests and working of this tower. The subject is divided into three parts—cooling surface, draught, and water distribution.

Cooling surface.—It is shown how the different kinds of cooling surface are applied and their value is examined. The principal agent in the reduction of temperature is evaporation. The cooling surface usually consists of wooden or metal frames, called mats, arranged inside the tower.

Draught.—The efficiency of a tower depends largely upon the draught of air through it to cause evaporation. There are two kinds of towers—one with natural draught, and the other with artificial draught, caused by a power-worked fan. Both are fully illustrated and described.

Water distribution.—This may be effected in various ways; the principal conditions being that the distribution shall be steady and uniform; hence a centrifugal pump is preferable to a reciprocating one.

The experimental tower is then described, as also the testing of same. A formula is given showing the relation between the cooling in degrees Fahr. and the weight of water condensed and the water circulated. The full capacity of the tower thus tested was for 950 gross HP.

The Paper is well illustrated by drawings and diagrams.

C. H. M.

A Cool Stoke-hole.

(Ingeniøren, Copenhagen, 1902, p. 30.)

At Horsen's Mill two Cornish boilers working continuously day and night, each with 395 square feet of heating surface, often got their furnace mouthpieces and fire-doors so hot as to glow red in the dark; and the boiler-house doors and windows had to be kept open summer and winter for enabling the stokers to do the firing. The manager accordingly devised a construction of double mouthpiece and fire-door, made of outer and inner plates with a wide air-space between. Ribs on the inner plates divide the space into a number of down-draught channels, through which the air, admitted at an opening on the top of the mouthpiece, passes downwards through both mouthpiece and fire-door, thereby keeping these cool while itself becoming heated in its passage through them, before it is delivered under the fire-bars. The ash-hole door is kept shut, so that all the air supplied to the furnace has to enter through the top opening, which is controlled by a damper. With this arrangement the temperature in the stoke-hole fell to that of the boiler-house; the back of the hand can be held against the fire-doors and mouthpieces, which are japanned; and the door latches feel quite cold. A thermometer hung 2 inches off the fire-door ranged between 57° and 61° F. There is also a considerable

saving in coal, due partly to the diminished radiation of heat and to the warming of the air admitted, but still more to the proper use of the inlet damper for regulating the admission. For marine boilers, and especially for Cornish or Lancashire, the plan is particularly suitable.

A. B.

Air-Resistance of Flywheels. SCHOLTES.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 1788.)

In the power-house of the Nurnberg-Fürther Tramway Company there are two horizontal compound tandem steam-engines of 450 HP. driving direct coupled dynamos. Heavy flywheels are provided, and the question arose whether an economy might not be effected by boxing over the H shaped arms, which had their webs in planes passing through the flywheel axis. The builders had expressed the opinion that the resistance of the air against the arms accounted for 2 per cent. of the work performed by the engines.

It was decided to test the effect of enclosing the arms so as to make each flywheel into a short cylinder with flat ends, and for this purpose the engine was disconnected from the flywheel and dynamo. The dynamo was then supplied with current and caused to drive the flywheel as a motor, the power required for this being calculated from electrical measurements. The arms of each flywheel were then boarded over and the dynamo again used as a motor to drive the flywheel.

With the arms opened and exposed to the resistance of the air the power absorbed was 13,300 watts, while, when they were covered over and relieved from air-resistance, this was reduced to 9,874 watts. At the steam-engine pistons this difference was equivalent to 5·7 HP., or 1·2 per cent. of the total output.

The Author further discusses previous experiments, one of which had shown a difference of 5 per cent.; also a formula which had been given for calculating the power required to drive the flywheel arms against the air. He suggests that the full length of the arms should not be taken in any proposed formula.

J. G.

High Speed for Belt Drives. DR. HEINR. ABBES.

(Zeitschrift des Vereines deutscher Ingenieure, 1901, p. 1638.)

From experiments[1] carried out by C. Otto Gehrckens on the transmission of power by belting, it came out clearly that when the number of revolutions was increased, the power transmitted

[1] Zeitschrift des Vereines deutscher Ingenieure, 1898, p. 15; 1900, p. 1509.

was increased in a greater proportion than the speed. When the increase of speed was obtained by changing the pulleys for others of larger diameter the ratio of increase of power that could be transmitted was greater than that to be obtained by raising the number of revolutions. For example, by altering the speed of a belt from 5 metres (16·4 feet) to 20 metres (65·6 feet) per second, the power was increased 5½ times, while if the same increase of speed was obtained by changing from 20-inch pulleys to others of 80 inches diameter, the power was multiplied 8 times. The two principal sources of loss in belt-driving are the work done in bending and unbending, and in the slipping of the belt on the pulley; these, and others less important, increase with the speed. The advantages to be gained by increased speed, however, not only make up for these losses but leave a considerable margin, so that the total gross effect of the heightening of speed must be very great. The Author gives reasons for believing that the tension which a driving-pulley can put on a belt is independent of the speed at which it is running. The explanation of the great efficiency of quick running must then be sought for in the distribution of tension on the pulleys themselves; and the Author, entering on a discussion of this, comes to the conclusion that, in order that a belt may transmit power to a driven pulley with the greatest possible efficiency, the speed at which it runs must be equal to the rate of propagation of the waves of stress in the belt. At a lower velocity part of the total tension is ineffective, and at higher velocities the increase of power transmitted will simply be in proportion to the increase of speed. Further, the more elastic the belt the lower is the speed of propagation of the stress and the better the transmission. A belt that is too tight loses part of its elasticity, and for ordinary speeds is very much worse than a slack belt.

J. G.

Ball-Bearings. Dr. F. HEERWAGEN.

(Zeitschrift des Vereines deutscher Ingenieure, 1901, p. 1701.)

The shafts of the three high-pressure centrifugal pumps of the Horcajo mine run on ball-bearings, withstanding a thrust of about a ton; and, with the exception of a few interruptions at the first, have run in a perfectly satisfactory manner almost continually night and day for over a year, without skilled attendance and in dripping underground chambers.

While the Author's experience has thus convinced him of the efficiency of ball-bearings, it has also led him to the conclusion that it is very difficult to get the proper qualities of metal in the bearings supplied.

The theoretical side of the subject is also considered in the Paper, and the treatment is based on the work of Hertz. Taking

first the general case of two perfectly elastic bodies with surfaces of the second degree pressed against one another with a force p, the normal passing through the original point of contact being taken for the z axis, the contour lines of the two surfaces with relation to the xy plane as datum will be ellipses. When the bodies are pressed together they touch one another over surfaces which are ellipses with axes parallel to those of the contour lines. The half axes of this contact ellipse are called a and b. The maximum intensity of pressure is, of course, at the centre of the surface of contact, and is equal to $\frac{3\,p}{2\,\pi\,a\,b}$. The Author gives methods of obtaining the values of a and b, and the amount α by which the surfaces approach one another.

In ordinary practice one of the surfaces may be a sphere, say of diameter d, and the other a plane. Putting k for the average pressure and introducing a coefficient H, the value of which for Stribeck's experiments was 31,800 kilograms per square millimetre (20,190 tons per square inch), and for the general case may be obtained from the following equation in which μ stands for Poisson's ratio :—

$$\frac{4}{\mathrm{E}}(1+\mu)(1-\mu)=\frac{16}{3\,\mathrm{H}},$$

the following formulas are applicable to the case of a ball-bearing on a flat plate :—

$$\frac{\alpha}{2}=\sqrt[3]{\left(\frac{p}{\mathrm{H}}\right)^2\frac{1}{d}}$$

$$a=b=\sqrt{\frac{p}{\mathrm{H}}\,d}$$

$$k=\frac{1}{\pi}\sqrt[3]{p\left(\frac{\mathrm{H}}{d}\right)^2}$$

The Author gives geometrical interpretations of the formulas, and finally enters more fully into the general case of bodies of any form.

One important question about which there is still doubt is as to whether the failure of balls is caused by pure crushing or by excessive local superficial tensile stresses. The general basis for the calculation of these tensile stresses is contained in the work of Hertz, but the Author has not succeeded in working out practicable formulas.

J. G.

Graphite as a Lubricant. C. CARIO and WAGNER.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1902, p. 53.)

This Paper contains separate reports by the two Authors on the tests made by them with the object of ascertaining the value of graphite as a lubricant. In the tests by Mr. Cario, which were made on a 25-HP. steam-engine, the use of an emulsion of oil and graphite was strictly avoided, and in the first tests the cylinder walls were lubricated by taking off the cover and strewing the dry graphite powder on the walls; the slide valve was lubricated by blowing the powder through a screw-hole in the valve-box and turning the engine by hand to expose all the parts in turn. This method was not very practical, and next was tried an emulsion of graphite and water. This was introduced into the current of steam entering the valve-box, a lubricating pump, with mechanical mixing and stirring, being employed. In spite of the energetic stirring, the graphite showed a great tendency to settle and choke the passages.

The Author concluded from his experiments that, in general, steam-engine cylinders are lubricated to an excessive degree, and that, with good construction and fitting, and when the steam is saturated, lubrication is not strictly necessary at all, while, for security, quite a small quantity of graphite is sufficient. The use of a graphite-oil emulsion offers few advantages, the lubrication with pure graphite being the method to be aimed at, as, besides being cheap, it gives an oil-free condenser-water and greater cleanness. The best method of applying pure graphite to surfaces to be lubricated remains to be discovered.

The experiments of Mr. Wagner were carried out with emulsions of oil and graphite, and the results were not favourable to the use of such emulsions from the point of view of expense and liability to interruption of the working of the lubricating arrangements, through settlement of the graphite in the passages. This Author's report contains full descriptions of his experiments, with a number of tabular statements.

J. G.

Driving Dynamos by Wind Power. POUL LA COUR.

(Ingeniøren, Copenhagen, 1902, p. 29.)

A horizontal shaft, driven from the windmill sails, drives through a vertical belt an intermediate shaft, from which a horizontal belt drives the dynamo. The bearings of the intermediate shaft are allowed a slight vertical play, enabling them to tighten or slacken the tension of the vertical belt without altering that of the horizontal belt; the latter tension is determined by a weight,

so as to transmit only the desired power to the dynamo. When a stronger wind would produce a greater pull on the vertical belt, it partially slips over the pulley on the intermediate shaft, and transmits a uniform power. The belt should be of leather, with the joint so made as not to cause any material variation in the slip; and it should be greased sufficiently to drive the smooth iron pulley by adhesion rather than by friction. There is then no occasion to doubt its working successfully. The heat produced by slipping is too inconsiderable to affect the durability of the belt; and the slip is not fitful. A 7-kilowatt dynamo (28 volts × 250 amperes), used for electrolysis, runs so steadily that no fluctuation can be detected in a volt-meter graduated in whole volts, and the ampere-meter shows scarcely 2 per cent. variation. A 6-kilowatt dynamo (150 volts × 40 amperes) has been similarly driven half a year for charging accumulators; an automatic switch is inserted between the dynamo and the accumulator, for breaking the current the instant it falls to zero, and for re-making it as soon as ever the dynamo voltage is again a trifle higher than that of the accumulator. This plan is entirely self-acting, and requires no supervision. When the wind drops, the charging ceases; as soon as ever it becomes strong enough, the automatic arrangement stores up everything between 0 and 40 amperes; and while, with ample wind, the slip prevents all overloading, this cannot be regarded as loss where wind is the power utilized. In default of an accumulator, the plan cannot be used for a variable supply of current; and recourse must be had to the automatic power-regulator [1] or "kratostat," which regulates for constant speed irrespective of load.

A. B.

Water-Tube Boilers, being the first part of the Report of the Admiralty Committee on these Boilers.

(Engineering, 28 February, 1902, p. 278.)

This report includes the complete results of the trials of H.M.SS. "Minerva" and "Hyacinth," and also a trial of the Cunard R.M.S. "Saxonia." The trials of the "Minerva" and "Hyacinth" were carried out so as to be, as far as possible, comparable mainly at powers of 2,000 HP., 5,000 HP., and 8,000 HP.; and a run was also made to Gibraltar and back at about 7,000 HP. The trial of the "Saxonia" was at 9,000 HP. from Liverpool to Queenstown. The report is accompanied by thirty-three Tables and numerous diagrams. The summary Table XXV. only is published here, as it really comprises all the main results detailed in other Tables. The "Minerva" has three-cylinder triple-expansion three-crank twin-screw engines of 8,000 HP., with ordinary cylindrical boilers, working at 155 lbs. per square inch. She had been four years in

[1] Minutes of Proceedings Inst. C.E., 1[illegible]1, vol. cxlv. p. 387.

service, but was thoroughly overhauled for these trials. The "Hyacinth" has four-cylinder four-crank triple-expansion engines of 10,000 HP., with Belleville boilers loaded to 320 lbs. per square inch pressure. She is a new vessel, which had not yet been in commission. She was specially prepared for these trials. The "Saxonia" is a large Cunard liner, with four-cylinder four-crank quadruple-expansion engines of 9,000 HP. to 10,000 HP., with ordinary cylindrical boilers working at 210 lbs. per square inch pressure.

The coal used and the furnace gases were analysed, and the whole of the water was measured, and all detail observations taken, as described in the report. The method of carrying out the trials is described. Every precaution was taken to keep the steam used by the auxiliary engines separate from that used by the main engines. Thirteen diagrams of results of observations are given. The thermal efficiency of the "Hyacinth's" boilers was in each case greater than that of the "Minerva's" at the same powers. The use of retarders in the "Minerva's" boiler-tubes was found distinctly advantageous, and brought up their efficiency nearly to that of those of the "Hyacinth." The boiler efficiency of the "Saxonia" was greater than that of the cruisers' boilers.

On all the "Hyacinth's" trials the great irregularity in water-level, as shown by the gauge glasses, which appears to be characteristic of the Belleville boilers, was very remarkable.

The accident to one of these boilers on the run home from Gibraltar appears to indicate the cause of that irregularity. This will be dealt with later on in the report.

C. H. M.

Water-Tube Boilers, being the second and last part of the Report of the Admiralty Committee on these Boilers.

(Engineering, 7 March, 1902, p. 326.)

Tables I. and XXVI. are here given. Table XXVI. gives the general results of the trials of H.M.S. "Hyacinth," H.M.S. "Minerva," and R.M.S. "Saxonia," as far as the main engines and auxiliary machinery are concerned. Not the least difficulty was experienced in maintaining the power on the full-power trials on either vessel. At the higher powers the jackets on the "Hyacinth" were found useless, and they were, therefore, disused. No similar trials were made on the "Minerva," but the jackets were disused on the run out to Gibraltar. On the whole it appears that the engines of the "Minerva" type can practically be made as economical in working as first-class engines in the merchant service. But the latter work most economically at full power (their usual working condition), whilst the vessels of the Navy work most economically at a little over half power. The actual thermal efficiency of the engines is given as 17·2 per cent. for the

"Saxonia," 16·7 per cent. for the "Minerva," and 15·1 per cent. for the "Hyacinth." Table I. gives full particulars of the hulls, machinery, etc., of the three steamers. The combined performance of the engines and boilers, as represented by the coal-consumption per I.HP.-hour, is given in Table XXVI., and is also shown graphically in a diagram. The Belleville boilers appear to fall off in efficiency as time goes on. The coal-consumption of the "Saxonia" was 1·29 lb. per I.HP.-hour, an economy which could hardly be expected in war-vessels. Tables XXVII. to XXXII. (in the report) give the principal figures of the detailed results of the run to Gibraltar and back. This run is then described in detail. The "Hyacinth's" boilers leaked a good deal, causing great loss of water. The coal-consumption was 2·08 lbs. per I.HP.-hour. The "Minerva" lost much less water, and her coal-consumption was 2·1 lbs. per I.HP.-hour. The ferrules at the fire-box end of the tubes got considerably choked with cinder and slag. The run home from Gibraltar was a full-power run for both vessels. On the "Hyacinth" one tube burst. It was found that it and others in the element of the boiler had been red hot. The water-gauge indications on the Belleville boilers are not reliable. After return to Portsmouth, the boilers were thoroughly examined. In the "Hyacinth" a number of tubes were slightly buckled, besides those in the element in which one had burst, and a number of slight leaks were found at various joints. In the "Minerva's" boilers there were no leaky tubes whatever, and only a few slight leaks elsewhere. The cap ferrules were all much closed by "birdsnesting." C. H. M.

An Instructive Boiler-Explosion. C. Bach.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 73.)

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1901, p. 802.)

The boiler, which exploded with very serious consequences, was a battery boiler 18 months old, consisting of four batteries of four superimposed slightly inclined cylinders, 750 millimetres (2 feet 6 inches) diameter and 7 metres (23 feet) in length, constructed originally of seven-sixteenths mild steel plate, and designed for a pressure of 170 lbs. per square inch. Shortly after the boiler had been erected and started working, one of the shell plates of an outside cylinder in the bottom row showed a bulge outwards on the underside at the fire end, about 16 inches in diameter and 4¾ inches in depth. The piece was cut out and the hole closed with a piece of plate. This repair did not prove watertight, and the whole thing was cut out and another patch riveted on. Naturally enough this was still ineffective and finally the whole of the lower half of the shell plate was cut away and replaced by a new plate. A few months afterwards the explosion occurred by the fracture of

the new plate. The Author was approached by the authorities with the request to make a special study and report on the causes of the explosion. His investigations included thorough tests of the strength of the fractured plate, and general consideration of the evidence given at the inquiry and of the reports of other engineers. The principal causes of the explosion seem to have been that the boiler was fed with condenser water, the new plate was of inferior quality, and the type of boiler was not good, especially in having the cylinders inclined downwards towards the fire. Another boiler of this type in the same works has since been done away with. J. G.

Geothermal Observations in Collieries.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. l., 1902, p. 158.)

In order to obtain trustworthy records of underground temperature in collieries, the Austrian Minister of Agriculture has issued a form to be filled in by the authorities at the various Austrian collieries. The particulars asked for include the number of bore-holes, the day and hour of the observation, the depth of the bore-hole below the surface, geological details, length of the bore-hole, condition of the bore-hole (wet or dry), interval of time between the boring and the thermometer reading, temperature in the bore-hole and in the air, and any other remarks that may appear necessary. The form is accompanied by detailed instructions. Temperature observations are to be made if a shaft attains a depth of 100 metres or more, in bore-holes at least 2 metres in length and as dry as possible. A maximum thermometer must be used, graduated in fifths of degrees from 0° C. to 45° C. The thermometer must be inserted about 24 hours after the completion of the bore-hole, and must remain for 2 days in the sealed-up bore-hole. The first reading must then be made, and the reading repeated daily until a constant result is obtained. The first observation should be made at a depth of 25 metres below the surface, and further observations should be made at every 50 feet deeper. B. H. B.

Temperature Measurements in Deep Bore-holes. H. THUMANN.

(Glückauf, 1902, p. 1105.)

For the determination of the geothermal gradient, that is, the depths that must be reached in order to find increments of 1° C. in the temperature, the geothermometer is employed. This instrument consists of a short thermometer open at the top filled with mercury, with a comparatively large receiver for the mercury. The thermometer is filled, at a low temperature, to the top with

mercury. On lowering the instrument into the bore-hole the increased temperature will cause some of the mercury to overflow. On cooling, the mercury again contracts. When the instrument is drawn up it is immersed in water at a lower temperature than that obtaining in the bore-hole, a normal thermometer being immersed with it. The water is then heated until the mercury in the earth thermometer rises to the top. The normal thermometer then gives the temperature of the bore-hole. Inasmuch as deep bore-holes are always filled with water, in which there is a circulation tending to equalize the various degrees of temperature, special precautions have to be taken to avoid error. Köbrich obviated such errors by preparing an isolated water column by the aid of india-rubber balls which were let down with the boring-rods, an operation which, with depths of 1,500 to 2,000 yards, occupied 24 hours to 36 hours. In carrying out temperature measurement in a bore-hole 5,300 feet deep at Oldau, the Author solved the difficulty by employing a cigar-shaped apparatus of thick tube, containing within it a cylindrical rod of wood in which three hollows had been cut to receive a thermometer each. Each thermometer was embedded in wool. This cigar-shaped case was simply dropped down the bore-hole. It fell slowly through the water and remained embedded in the mud at the bottom. The mud prevents circulation of the water. The case was then bored over and was brought to surface with the core. As the lowering of the rods down so deep a hole occupies 6 hours to 10 hours, the thermometers have ample time to acquire the temperature of the rock.

B. H. B.

The Freezing Method of Sinking Mineshafts in Limburg.

T. Koster.

(De Ingenieur, 1901, p. 457.)

The formations overlaying the coal measures in Limburg mostly consist of sandy and porous strata, very wet and difficult to deal with. Latterly the old practice of sinking shafts has been more and more abandoned, and the freezing system applied in the construction of the shafts near Eygelshoven. For this purpose a number of bore-holes were driven down, laying in the circumference of a circle of about 6 feet larger diameter than that of the intended permanent shaft, and from 2 feet 6 inches to 3 feet 4 inches apart. Down these holes the freezing mixture (magnesium chloride) is poured through tubes. After two or three months the soil round the bore-holes is frozen and a hollow ice cylinder formed with sides 3 feet thick. The cone is then excavated down to the sandstone overlaying the coal seams, and a shaft lining built up from below. The cost of such works comes to about £160 to £200 per yard depth. Several drawings illustrate the Paper.

H. S.

Australian Coal.

(Engineering, 4 April, 1902, p. 446.)

An official report has been issued on the anthracite coal deposits of Queensland. Although coal is found in each of the Australasian Colonies, the quality varies very much. New South Wales is best off because its coal mines are near the shipping ports, and a widespread connection has been established with the other Colonies and the west coast of America. The Queensland anthracite extends over an area of 5,000 square miles, and the Central Railway, running from Rockhampton to the interior, passes right through the coalfields. The carbon value is 78½, with an ash residue of nearly 5. The calorific power is much above that of New South Wales coal. The Queensland coal deposits, at present known and worked, cover 21,400 square miles, and much more coal is known to exist. The quality varies very much, some being inferior to the New South Wales coal. Exports of coal from Newcastle (New South Wales) last year reached 3,104,735 tons. Last year the output of all the New South Wales mines reached 5,650,000 tons, against 4,706,000 tons in 1898, and 3,203,500 tons in 1890. The mines of New South Wales cover an area of 24,000 square miles. New Zealand ranks after New South Wales in coal production. The cost of carriage to market militates against the development of considerable deposits in Tasmania; nevertheless the output is increasing. In West Australia coal has been discovered at several points, and systematic exploration is proving the existence of considerable deposits at many places in the Colony. In Victoria the coal industry is making rapid progress, though it is likely to be some time yet before local mines can supply the wants of the Colony. The most important deposits lie in Gippsland; they are supposed to contain 34,000,000 tons of coal.

C. H. M.

On Combinations of Iron and Silicon. P. Lebeau.

(Annales de Chemie et de Physique, vol. xxvi., 1902, p. 5.)

The Author has studied the composition of the different compounds of iron and silicon by a method which was discovered accidentally in the production of glucinum by the electric furnace. This consists in heating mixtures of iron with twice its weight of commercial cupro-silicon, or copper containing about 10 per cent. of silicon, in a Doulton crucible lined with carbon for several hours in an air-furnace, fired first with coke, and subsequently with gas-retort carbon. The melted product, which is of a bronze colour, and almost malleable, is treated with 10 per cent. nitric acid, which dissolves away the cupreous portion, leaving a crystallized residue whose composition is Fe_2Si, fusible at about 1,200 degrees

Centigrade to a crystalline mass resembling white cast-iron. By increasing the proportion of cupro-silicon to iron more highly silicized compounds are obtained up to about 33 per cent. of silicon. These are divisible into two parts, one magnetic corresponding to Fe_2Si, and the other iron magnetic of the composition FeSi. This is harder than Fe_2Si, and is less readily acted upon by acids. A third silicide of the composition $FeSi_2$ has been obtained by heating metallic-iron in the electric furnace with five times its weight of silicon and carbon-silicide when a residue is obtained in small crystals of a density of 5·4, and a hardness between that of fluor-spar and apatite. This appears to be the highest compound obtainable. The composition of the three compounds is:—

—	Silicon.	Iron.	Specific Gravity.	Hardness.
Fe_2Si	20·0	8·0	6·85	6·5
FeSi	33·3	66·66	6·17	8·5
$FeSi_2$	50·0	50·0	5·40	4·5

In commercial ferro-silicons containing less than 20 per cent. of silicon that element is present as Fe_2Si dissolved in iron. Those with 20 per cent. to 33 per cent. contain both Fe_2Si and FeSi, those above 33 per cent. both FeSi and $FeSi_2$, and those above 50 per cent. $FeSi_2$ with excess of free silicon. In ordinary dark grey foundry-iron with a maximum of 4 per cent. of silicon, Fe_2Si is present dissolved in excess of free iron as a perfectly homogeneous solution when solidified.

H. B.

The Alloys of Aluminium and Magnesium. O. Boudouard.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 31 December, 1901, p. 773.)

The former experiments of Wœhler and Parkinson are discussed, and the Author points out that Mr. Mach had recently produced an aluminium alloy, with from 10 to 12 per cent. of magnesium, which was lighter than aluminium itself, had the colour of silver, and was capable of being turned, bored and screw-tapped. A series of experiments are here recorded with alloys containing various percentages of each metal, which the Author has examined by the microscope and by other methods recently introduced. In each case he dealt with 10 grams of materials, which were treated in green glass tubes in an atmosphere of coal-gas or pure hydrogen. The temperatures were ascertained by means of Chatelier's thermo-electric couple, under precautions which are here explained. The metals were in all cases heated to a temperature in excess of that

needed for their perfect fusion, and they were then allowed to cool, and the temperature curves were plotted at regular intervals of time. Starting with pure aluminium, and gradually increasing the percentage of magnesium, the alloys become more and more brittle up to even mixtures, and those containing from 0 to 15 per cent. of either metal could alone be of interest from the aspect of their malleability. A great number of alloys were prepared for microscopic study, and owing to the ease with which magnesium burns in atmospheric air it was found very difficult to produce ingots of alloy which contained anything approaching the weights of the metals employed, even when they were fused under chloride of sodium and charcoal. Several micrographic photographs are given of certain alloys, showing a crystalline structure; in these the composition was approximately Al_4Mg. The specific gravity of this alloy was 2·58, and a number of different specimens gave the following exact composition on analysis:—

Aluminium . . .	81·5	82·3	83·2	80·4
Magnesium . . .	18·9	17·5	16·8	19·6

Other alloys containing one part aluminium to two parts of magnesium, and equal parts of both metals, were also examined.

G. R. R.

A General Irrigation Scheme for the Island of Java.

H. H. van Kol.

(De Ingenieur, 1901, p. 341.)

The advantages of irrigation are so evident that it would be unnecessary to draw attention to it but for the disaster which overtook the Solo irrigation works, shaking confidence in similar proposals. Although great famines, such as those of recent years in British India, have not occurred in Java since 1849, the area of irrigated rice-lands is inadequate in ratio to the increasing population. It was after the terrible famine, through failure of the crops in the plains of Demak, near Samarang, that the first works for irrigation were started; the public opinion being then forcibly awakened by the undescribable suffering and the serious consequences. Since then the first zeal has abated, although an increasing population require additional cultivable lands. Even now there is scarcity and famine in most districts in the last weeks before the harvest, which is unpardonable in a country with large tracts uncultivated and a yearly average rainfall of from 60 inches to 180 inches. During the last twenty years the population has increased by 20 per cent., while the area under rice cultivation has been only extended by 3 per cent. The Author proposes that the policy of irrigation should be at last taken in hand seriously, a general plan of the whole subject be

worked out, subdivided into 15 sections, each treating a separato river basin so as to avoid in future the haphazard fashion hitherto followed. A plan is added to the Paper showing a comparison between areas irrigated in British India and in Java.

H. S.

Water-Supply of Certain Sea Resorts on the German Ocean.

HERZBERG.

(Gesundheits-Ingenieur, 30 November, 1901, p. 359.)

Reference is made to the difficulties to which certain of the watering-places on the shores of the North Sea, and on sandy islands lying off the coast, are exposed in the matter of water-supply. Owing to the great rise and fall of the tides, amounting to nearly 10 feet, the condition of the subsoil water constantly exposed to these daily changes of tidal level is very different from that which prevails on the nearly tideless Baltic, and the influence of the salt water is felt much further inland than is the case where tides are absent. The recent tendency of summer visitors to the seaside resorts has been to get as close to the sea as possible, and large towns have sprung up like Norderney on the outlying sand-dunes. Some twenty years ago Norderney was supplied with water from two sources—first by storing up the rainfall from the roofs in wooden or masonry tanks near the houses, and secondly by excavating shallow wells in which the subsoil water collected. This latter water, apart from its high percentage of salt, is not unwholesome, but it is almost invariably tinged with a brown or yellowish colour, owing to the layers of turf-like remains of sea-weeds which traverse the whole of the island of Nordeney at depths of from 6 to 16 feet. It was obviously imperative under the above conditions that, as population increased, all sewage water should be removed as quickly and as thoroughly as possible. The Author laid down the axiom that no efficient water-carriage system was possible in the absence of an ample and constant supply of pure water, and that sea-water could not be employed for sewage purposes with advantage. In the search for a suitable supply, the Government voted £1,000 for boring operations, and the first bore-hole was put down in the centre of the island, which, at the point selected, is about 1¼ mile in width. It was not until a depth of 196 feet was reached that brackish water was encountered, and on a pumping trial extending over eighty days, on each of which 132,000 gallons of the sweet water found in the upper layers was withdrawn, the fact was established that over the whole island a vast cup-shaped volume of sweet water, with from 100 to 160 milligrams of salt per litre, rested on the salt water found at the deeper levels. The Author explains that, in consequence of the greater specific gravity of the salt water, the rainfall as it sinks

into the ground floats above the salt water in the porous sandy soil and does not become notably salt. Owing to this circumstance a good supply of fairly pure water has been obtained.

G. R. R.

The Means by which Water is Freed from Iron.

BERNHARD TEUFER.

(Gesundheits-Ingenicur, 15 April, 1902, p. 105.)

In the various processes in use for the purification of water containing iron salts in solution, reliance is chiefly placed on the so-called aeration of the water, combined with subsequent filtration. The Author states that, in common with many other operators, he had found the process to work to the utmost advantage when the gravel-filter was covered with a considerable amount of the ferruginous mud deposited from the water. He therefore took care never to remove all the mud from the filters, and endeavoured to ascertain the exact conditions under which the precipitate acted upon the dissolved iron. Certain authorities regarded this as a species of "contact action" between the hydrated oxide of iron and the iron in solution. For some time he was disposed to consider that the hydrous oxide on the filter exerted a species of magnetic attraction on the dissolved iron. Some time ago he came to the conclusion that the process of aeration was not needed, and that it sufficed to stir up the water with a considerable quantity of hydrated oxide of iron, and then to separate the mud from the clear liquid. In order to prevent the access of the oxygen of the air to the water under treatment, he arranged to carry out the process in such a way that air was wholly excluded, and on admixture with the necessary amount of hydrated oxide of iron, the water was instantaneously deprived of its dissolved iron, and the result was in all cases the same, whether the iron in solution was combined with carbonic, hydrochloric, sulphuric, acetic, tartaric, or humic acids—in fact, with every salt of iron tested in solution. None of the text-books consulted by him furnished an explanation of this reaction. It had been noted that the removal of the iron in solution was expedited by the presence of freshly-precipitated hydrated oxide of iron, but no observer had announced that the simple addition of the hydrate was all that was necessary. While no definite deductions could be drawn from dissolved carbonates, the Author found on experimenting with acetates of iron that, on exposure to the hydrated oxide of iron precipitate, a basic acetate of iron was in the first instance thrown down, and in the same way he proved that all other salts of iron are at first produced as basic salts. The part played by the atmospheric air is continuously to regenerate the hydrous protoxide of iron into the peroxide, by means of its oxygen, and thus to render the precipitated mud capable of acting upon fresh volumes of water.

Hopes are held out that it may be possible to render the Author's discovery available for the treatment of certain descriptions of ferruginous waters which have hitherto resisted the ordinary processes.

G. R. R.

The Hünermann Process for Disinfecting Water. Dr. Schüder.

(Zeitschrift für Hygiene, 1902, p. 379.)

The Author discusses the various chemicals which have from time to time been proposed for destroying germs and rendering water wholesome, and he points out that Schumberg had already suggested the use of bromine in the form of a bromide of potassium solution, containing a small proportion of free bromine. Pfuhl pronounced a favourable opinion on this process[1] and Ballner had shown that bromine acted well as a sterilizing agent. For reasons that are here explained in detail, the Author was led to believe that in some respects the former conclusions were inaccurate, and he resolved to undertake a fresh series of experiments with the Hünermann process, in which a larger volume of the water should undergo treatment, and the micro-organisms should be submitted to culture-tests in various ways. Under Hünermann's system a 10 per cent. solution of chloride of soda is employed, and in all cases determinations were first made of the contents in chlorine before use. To remove the superfluous chlorine, a solution of sodium sulphite prepared by the Author was invariably used. The precautions taken to carry out the various experiments are set forth. Four different kinds of water, representing the chief varieties of hardness, impurity, etc., were selected for the tests, viz. distilled water, spring water, service water, and canal water. To each of these samples mixed with the chloride, test-cultures of cholera vibrios and the bacilli of typhoid fever and diarrhœa were added in stated proportions, and the results were compared with the untreated samples of the same kinds of water. The various sets of tests are arranged in a tabulated form, and the Author states that the process appears to reduce to a very marked extent the vitality of the germs, even in highly polluted samples of water; in some instances the water was rendered germ free. The cholera vibrios were in a few of the tests wholly destroyed; but neither in the case of cholera nor typhoid fever germs was the treatment entirely reliable. Even the bacilli of diarrhœa, which are much more susceptible than most other pathogenic germs, were not killed in all cases. Hünermann's process yielded better results on the whole than that of Schumberg. The Author appends a series of conclusions bearing on the merits of plate-cultures and other matters needing special attention.

G. R. R.

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[1] Minutes of Proceedings Inst. C.E., 1901, vol. cxli. p. 391.

Sewage Purification and Water Pollution in the United States.

(Engineering News, 3 April, 1902, p. 275.)

The present extent of sewage purification in the United States is partly shown by a Table of ninety-five cities and towns, with a population of three thousand and upwards, which is given. About nine years ago only thirty-one cities and towns in the United States had sewage purification works, according to a list then published. Each list contains a number of Western towns where all the sewage is utilized for irrigation purposes, and not treated from sanitary motives. The Table gives the method used for the disposal of the sewage. The method of sewage purification principally in favour at first was intermittent filtration. Table II., which is a classified summary of Table I., shows that this method still takes the lead, numbering twenty-four cities and towns against nine for broad irrigation and sewage farming, and seven each for septic tanks and chemical precipitation. Besides this, in some places septic tanks are combined with other methods of purification. Chemical precipitation never made much headway in the States, and at present it is almost at a standstill. The septic tank is comparable with chemical precipitation, but is more popular, because it entails no expense of chemicals, and, it is claimed, comparatively little labour or expense for sludge disposal. Contact and bacteria beds cannot yet be spoken of with much confidence. A careful examination of the whole list of ninety-five places indicates that, say, sixty places in the United States, with a population of three thousand and upwards, have really creditable sewage-purification plants; but the number is increasing rapidly. Table III. gives a list of lawsuits for water pollution which shows that this increase is inevitable.

C. H. M.

The Sewage-Purification Works of Düsseldorf.

(Gesundheits-Ingenieur, 28 February, 1902, p. 61.)

The municipal authorities of Düsseldorf are of opinion that the amount of the impurities present in the sewage water, after treatment by simple deposition, is so small that no serious nuisance could arise by its discharge into the Rhine, which, even at the lowest winter flow, is equivalent to a volume of 146,000 gallons per second. The volume of sewage at the outfall for a population of 200,000 persons would be, if the water-supply is fixed at 33 gallons per head per diem, only 88 gallons per second, or, assuming an increase of the population to 300,000, only 118·8 gallons per second. The sewage would thus be diluted with from 1,600 times

to 1,200 times its volume of river water, and the effect of the sewage discharge on the river would be of little or no consequence, either upon sanitary or æsthetical grounds. When the rapid flow of the Rhine is taken into account, it would seem to be sufficient if the grosser suspended impurities were retained in tanks, and if provision was made to retain the sand and deposited matters in catch-pits. Unless the solid matters are removed there is always the danger of the formation of mudbanks and shoals at the outfall, and these might become decomposed and give rise to noxious emanations, but the same troubles are encountered if the sewage sludge is allowed to accumulate in tanks or pits. In the case of the sewage water of Cologne, it has been decided not only to remove the suspended impurities by simple deposition, but also to clarify the polluted water before it enters the river. With a 2,000-fold dilution of the sewage water this further clarification does not appear to be called for. It is pointed out that the populations of the Rhine below Cologne do not use the water for drinking purposes. Dr. Kruse, of Bonn, has expressed the opinion that the Rhine would suffer no injury if all the sewage schemes of the various towns on its banks were carried out. It would seem that each of the five government departments concerned have given their consent to the course of action laid down by the Düsseldorf municipal authorities.

G. R. R.

Filters for Sewage Water on Puech's System. H. FONTAINE.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 31 January, 1902, p. 13.)

A plan of constructing filters capable of dealing with large volumes of water in a small compass has been devised by Mr. A. Puech, of Mazamet. It consists in its essential features of three rectangular chambers, constructed in masonry, ranged side by side, which are each of them floored over at about two-thirds of their depth with perforated iron plates, resting on double T-iron supports, which plates are covered to a given thickness with gravel screened to pass sieves of a stated size. The iron plates are 0·15 inch in thickness. The stones of gravel in the first chamber vary from 0·47 inch to 0·59 inch in diameter; those in the second chamber are about 0·39 inch in average size; and those in the third chamber from 0·23 inch to 0·31 inch in size. The depth of the gravel at the near end is 13·77 inches, and at the farther end 7·87 inches, to give a fall of about 6 inches. A section of this filter is appended. These chambers are provided with a series of valves, so arranged that the sewage water can enter the first chamber and pass through the gravel to the hollow space beneath, then be let into the second chamber, and finally into the third chamber. After treatment in the three chambers the process of purification can be completed on ordinary sand

filters. There is a difference of 3·9 inches between the surface of the water in the first and second chambers, and the same difference in the water-levels of the second and third chambers, which is sufficient to render the filtration continuous. In each 24 hours, 613 gallons of sewage water are passed successively through each square foot of combined filter area. The surface of the filter requires to be cleansed every 8 days, but the valves enable one chamber at a time to be shut off while the cleansing is in progress, and the water then only traverses the other two chambers. From some tests made at Ivry with the water of the River Seine, this treatment reduces the number of bacteria in the effluents from one-half to one-twentieth of those originally present. It is stated that filters on this system are being constructed at Ivry for the Paris sewage, at Nice, at Nantes, and two for the treatment of the Thames water by the East London Waterworks Company.

G. R. R.

The Duration of Vitality in Disease-Germs Conveyed in Particles of Spray or Dust. Dr. FRITZ KIRSTEIN.

(Zeitschrift für Hygiene, 1902, p. 93.)

Reference is made to the previous communication of the Author,[1] in which he showed that the bacilli of prodigiosus and typhoid fever, dispersed with the finest particles of spray and exposed to diffused daylight and to the atmosphere, died within the space of about 24 hours. Further experiments with the rose-coloured hay bacillus led him to the belief that certain germs could retain their vitality under the above conditions for as long as 10 or 14 days, and these facts pointed to the necessity of additional experiments with other pathogenic micro-organisms, which might be diffused abroad as spore-free bacteria, in order to ascertain whether some bacilli were under ordinary conditions more capable of enduring exposure than others. He therefore selected for another series of tests the bacilli of diphtheria and tuberculosis, as also those of chicken cholera, together with staphylococci and streptococci and the spores of anthrax. These were distributed by means of fine spray, and also associated with the most minute particles of dust. The results are set forth in tables, and diagrams are given of the apparatus employed. The various experiments show that the duration of vitality is greatly increased if the bacilli are excluded from exposure to diffused daylight. Thus the spores of anthrax which manifested the greatest vitality under all conditions died in daylight in 10 weeks; but when preserved in a cellar they retained their vitality for at least 3 months. The bacilli of chicken cholera, which proved to be the least resisting of the

[1] Minutes of Proceedings Inst. C.E., vol. cxliv. p. 378.

micro-organisms, died in daylight in 10 hours, but in the cellar lived for 24 hours. The above tests were all arrived at by spraying, associated with fine particles of moisture. When disseminated with fine dust, the duration of vitality was, under similar conditions, in all cases considerably longer.

G. R. R.

The Epidemic of Typhoid Fever at Riga in 1900.

Dr. W. von Rieder.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1901, p. 577.)

An account is given, with many graphic diagrams, of the outbreak of typhoid fever at Riga, which attained to alarming proportions in June 1900. The cesspit system prevails throughout the town for dealing with the excreta, and the contents of the cesspools are conveyed away from time to time in air-tight casks or vessels to the works situated in several outlying districts, where the fecal matters are stored, partly in great covered basins, and partly in the open air for admixture with house-refuse, peat, earth, or sand, in order to produce a compost for removal by the farmers. There is also in Riga a drainage system for foul water, from which all excretal matters are excluded, in order to carry off the rainfall and the surface water into the River Düna. The town, which has a total population of about 300,000, is supplied with unfiltered water from the River Düna, distributed by the municipal waterworks; but about half of the population is dependent for its water-supply on shallow wells or artesian borings. By reference to a plan the Author shows that the municipal supply is derived from a point in the stream above the inhabited area, but an old intake, situated within the so-called delta in the centre of the town, is sometimes used when the river-water is thick and muddy. The water in the delta, being to some extent impounded by dams, gets cleared by simple deposition. As shown by a Table, typhoid fever is endemic in Riga, but until May 1900 there was nothing exceptional in the number of cases. The height of the outbreak on June 5 pointed to May 18 as the time of infection. In the month of June there were 868 cases, with 107 deaths. From this time onwards the disease decreased steadily until December, when the number of cases was again normal. All the facts as to water-supply, and sex, age, occupation, status, etc., of patients, are fully investigated, and the Author arrived at the following conclusions. This outbreak is a most striking instance of the origin of typhoid fever due to an infected supply of drinking-water. The provision of a supply of unfiltered and impure river-water exposed to pollution is a standing menace to the health of the inhabitants of the town. Every patient can

effect the spread of the disease, and it is thus of vital importance that all cases of typhoid fever should at once be reported by the physician, in order that due precautions may be taken.

G. R. R.

The Use of Alcohol for Lighting and Heating Purposes.

M. LINDET.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 28th February, 1902, p. 148.)

It is pointed out by the Author that the cultivation of beet-root, which is so indispensably necessary for the well-being of French agriculture, is now threatened by the over-production of sugar, and that while the demand for sugar is limited, that for alcohol, if regarded as a competitor with foreign petroleum as a source of illumination, heating, and motive power, is practically unlimited. Acting on this belief, the French Minister of Agriculture has instituted a competitive trial of every kind of apparatus employing methylated spirits of wine for lighting and heating purposes. The apparatus in question may be classified broadly under two heads—those in which the spirit is consumed at the extremity of a wick, and those in which it is previously vaporised and then burnt in gaseous form. Alcohol-lamps are well known in which the liquid is drawn up by a cotton wick and lighted at the top in the presence of a double current of air. As alcohol alone has no value whatever as an illuminant, it has to be mixed with benzine in the proportion of from 25 per cent. to 35 per cent. of the latter. According to the tests of Mr. Couderchon, the best of these lamps required from 5 cubic centimetres to 7 cubic centimetres of carburetted spirit per candlepower-hour. For heating purposes the ordinary spirit lamp, with its round wick dipping into the liquid, is thoroughly familiar and is a relatively economical source of heat. In respect to the various types of apparatus in which the alcohol is burnt in the gaseous condition, the principle in general use involves the employment of a small boiler or heating chamber in which the spirit is volatilised. The spirit is generally conveyed to this boiler *per ascensum*, either by capillary action or by internal pressure on the surface of the liquid in the reservoir caused by the dilation of heated air, or by means of a pump. It is, however, in certain contrivances brought to the boiler *per descensum*. The gaseous alcohol issues under considerable pressure and is consumed in a Bunsen burner, which is surmounted by an Auer mantle. A description follows of very numerous different types of lamps in which this principle is employed. Illustrations are given in order to describe their action and to explain the chief outlines of their construction. The various kinds of heating apparatus which make use of volatilised spirit are similarly dealt with, and a comparative

Table is given of the volumes of spirit necessary to produce a definite amount of illumination or a measured degree of heat. In conclusion the Author contrasts the cost of methylated spirits for the above purposes as compared with that of electricity, coal-gas and petroleum, and he points out certain advantages and defects inherent in the use of this liquid.

G. R. R.

Central Heating Plants in the United States.

(Engineering News, 20th March, 1902, p. 231.)

The rapid centralization of all kinds of industries is well illustrated by the recent growth of commercial central heating stations. There are at present eighty-two central heating stations actually at work in the United States—a Table of which is given. The term central heating station is used to denote plants which supply steam or hot water heating for commercial gain, and that term does not include plants for the service of institutions and industrial establishments, nor for heating by artificial or natural gas, nor by electricity. Of the total number of eighty-two plants, thirty-seven are worked independently of any other service, whilst forty-five are worked in combination with electric light, gas works, railways or water works. Table II. gives the distribution of the Central Heating Stations by totals as well as by independent and combined plants, and Table III. enumerates other services in combination with which the forty-five Central Heating Stations are worked. The combination of electric service, whether lighting or railway, with central hot water or steam heating is of comparatively recent date, and bids fair to be one of the features of municipal life in the near future. The most uncertain elements of cost seem to be depreciation and maintenance charges.

C. H. M.

The Resistance to Penetration of Elastic or Non-Elastic Materials. ÉDOUARD SIMON.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, March, 1902, p. 337.)

After calling attention to the imperfect results obtained by means of tensile tests on strips of elastic materials in the manner commonly practised, the Author describes and illustrates an apparatus devised by Mr. Jules Persoz, which obviates some of the defects in question. Instead of a narrow strip of say 2 inches in width, held at either extremity by jaws, capable of being extended in such a way as to test both the weight applied and the elongation of the sample

under test, Mr. Persoz employs a disk of the substance to be tested, which is firmly strained over a metal frame between two metal rings, so as to resemble the head of a drum. In the centre of this well-stretched surface, a plunger is so arranged as to be forced forward until it ruptures or penetrates the material under test. The head of the plunger may be either spherical, conical or flat, giving in each case results which are slightly different. The most uniform tests are obtained by the use of a sphere, the diameter of which is to the approximate width of the disk under test as 4 is to 5. In textiles the size of the sphere employed greatly influences the ultimate results. Thus, in the case of a disk of cloth 2 inches across, the force needed to effect perforation varies from 42 lbs. to 152 lbs. if the diameter of the spherical head of the plunger is increased from 0·39 inch to 1·57 inch. Tables are appended giving the results in the case of various materials tested in this apparatus, and contrasting them with those obtained when the material was tested as strips in the ordinary way. Tests are given of metals, paper, cotton and woollen-cloth, etc., with photographs illustrating the nature of the injury when perforated. The machine is capable of registering both the weight or pressure needed to effect perforation and the flexure as indicated by the forward movement of the plunger.

G. R. R.

Thermo-Electric Measurement of Stress. C. A. P. Turner.

(Proceedings of the American Society of Civil Engineers, January, 1902, p. 26.)

This Paper describes two methods of measuring stress by thermo-electric means; the first by relative measurement of the temperature change in the bar when the load is applied or removed, and the second by measurements indicating the extent of the temporary change in the thermo-electric intensity of the bar, due to the stress applied. The Author claims to have reduced the first to a basis approaching scientific accuracy, and to have proved the practicability of the second. In the first method the thermal measurement of stress depends on the theory of thermo-elastic properties of matter developed by Lord Kelvin, and assumes the principle that, if two loads, of different magnitudes, are gradually applied in equal periods of time, the temperature changes in the bar, for the respective loads, will be strictly in proportion to the loads.

The apparatus consists of a thermopile attached to and insulated from the bar in which the stress is to be measured, and in circuit with a suitable galvanometer, provided with a scale and telescope for reading the deflections. Results of measurements of tensile stress by this method are given.

A. W. B.

Machines for Spinning Artificial Textile Fibre.

R. W. STREHLENERT.

(Teknisk Tidskrift, Stockholm, 12 October, 1901, p. 287.)

When designing and constructing in Paris in 1895 a model for a new machine for manufacturing vegetable silk, the two objects the Author aimed at were that its working should be continuous, and should also be independent of the strength of any one of the individual threads from which the combined fibre is spun. Instead, therefore, of drawing the threads upwards from below during the spinning, as in previous attempts, he practically inverted the spinning part of the machine so as to draw them downwards from above, thereby enlisting the aid of gravity in the process. The fine threads of viscous liquid issuing from twenty minute nozzles, which are arranged in groups in a horizontal disk, are drawn down through water contained in a conical funnel beneath, wherein they converge to the bottom, and are spun together both by the groups of nozzles severally revolving in the disk and by the disk itself revolving bodily. From the bottom of the funnel the compound fibre so spun is drawn off through a rising tube, and wound upon a bobbin. If any thread breaks in the funnel, its broken end gets caught in amongst the rest, and the spinning is not interrupted thereby. The viscous liquid is supplied to the machine under a pressure of 8 atmospheres, whereby a continuous flow from the nozzles is maintained. Two such machines, each containing twelve spinning funnels, were made in Stockholm in 1896–7 for the late Dr. Alfred Nobel. Each of the twenty-four bobbins is $4\frac{3}{4}$ inches diameter, and runs at 100 revolutions per minute, reeling about 28 miles or $2\frac{1}{4}$ lbs. per bobbin per hour. Under a heavier pressure the speed and production can be increased to half as much more. Owing to its cost, the solution employed for gelatinizing the nitrocellulose is recovered from the water in the spinning funnels to the extent of 82 per cent., which is used over again with the addition of 18 per cent. of fresh solution. The working of these machines demonstrated the importance of placing the nozzles as close together as possible. Instead, therefore, of a revolving disk carrying detached groups of nozzles also revolving separately in it, the Author devised a single rotating headstock or mouthpiece containing the whole of the orifices, which is constructed by melting together alongside one another a number of capillary glass tubes, and melting the group into the end of a larger glass tube. The holes are afterwards ground out to gauge, for ensuring the same outflow through each. Thus greatly simplified, the machine works automatically and uniformly from the start, and requires the least possible attention. A yet further simplification consists in keeping the headstock or mouthpiece stationary, and giving a whirling motion to the contents of the funnel, by delivering the

coagulating liquid into it in a jet directed tangentially to the inside of the rim. The several plans described are elucidated by illustrations.

A. B.

Chardonnet, Pauly, and Millar Artificial Silk Threads. R. W. Strehlenert.

(Teknisk Tidskrift, Stockholm, 19 October, 1901, p. 296.)

The Chardonnet, Pauly, and Millar processes are described, and the distinctive features of the three are discriminated. The cellulose employed in the Chardonnet pioneer process of 1887, which is carried out at Besançon in France, and elsewhere, is first nitrated and afterwards denitrated, undergoing thus a complete conversion twice over, for first enabling it to be dissolved and spun, and for subsequently restoring it to its original condition. This indirect method of arriving at the final result was followed ten years later in 1897 at Gladbach by the Pauly plan, according to which the cellulose is dissolved in a solution of copper oxide and ammonia, without previous treatment, and the artificial silk is spun therefrom direct. From glue or gelatine dissolved in water Millar in Glasgow spins threads which coagulate in air, and when wound on bobbins are exposed to the action of formaldehyde, for rendering the gelatine insoluble. The silk so made, though much inferior to that of vegetable origin, has come into use especially in England; the cost of manufacture is considerably lower.

A. B.

Viscose Artificial Silk Thread. R. W. Strehlenert.

(Teknisk Tidskrift, Stockholm, 19 and 26 October, 1901, pp. 298 and 301.)

Viscose silk, manufactured by Cross and Co. at Kew, owes its production to the discovery by Mercer, nearly sixty years ago, of a compound of cellulose and caustic soda; and to the further discovery in 1895 by Cross, in conjunction with Bevan and Beadle, that this compound when exposed to carbon disulphide forms a substance completely soluble in water; the solution thus obtained is called viscose. The proportions which the Author has found best for the ingredients are—cellulose 27, caustic soda 9·6, water 48·4, carbon disulphide 15 per cent. The caustic soda solution is first well worked into the cellulose, and the carbon disulphide is then mixed therewith in an air-tight vessel. At about 20° C. or 68° F. a reaction sets in, which lasts about an hour; the mass shrinks considerably, turns yellowish brown, and is then ready for dissolving in water.

The liquid contained in the spinning funnel, into which are

delivered the minute threads of viscose solution issuing from the press nozzles, was originally a solution of alcohol or of sodium chloride (common salt). The viscose on precipitation therein from its solution assumed a semi-liquid state only, and hardened so slowly that the several threads stuck together, and no suitable textile fibre could be obtained. In 1898 the discovery was made by Stearn at Kew that solutions of ammoniacal salts, such as ammonium chloride (sal-ammoniac), precipitate the viscose from its solution in such a way that it hardens instantly to the desired extent, and the threads have no tendency to stick together; they can be drawn from their nozzles at the rate of 330 feet a minute (3¾ miles an hour) and upwards. The success is due to the fact that the sal-ammoniac removes the caustic soda from the solution of viscose, and the latter is simultaneously deprived of its water; the cellulose is at first converted into a substance free from alkali, containing between 10 and 17 per cent. of sulphur, and possessing sufficient homogeneity, elasticity, and strength to admit of its being drawn and spun into fine and glossy thread. After being deprived of its sulphur in a bath of sal-ammoniac, and then bleached, it is greatly superior for textile use to silk made from nitro-cellulose, both in gloss, strength, and elasticity; it is also the stronger of the two when both are wet. As cellulose can be produced cheaply from sawdust, it should form the basis for an important manufacture of viscose in Sweden; and an outline is given of the process to be followed.

A. B.

Strength of Natural and Artificial Silk Thread, and of Tissues Woven therefrom. R. W. STREHLENERT.

(Teknisk Tidskrift, Stockholm, 2 November, 1901, p. 307.)

In its raw state natural silk consists of fibrin or pure silk thread, with an albuminous gummy coating of sericin. The latter, commonly called "bast," and constituting from 25 to 30 per cent. of the weight of the raw material, is boiled off in hot soapsuds before the silk is dyed. The original weight before boiling is taken as par; and the pure boiled off or "scoured" silk is loaded up to par, before the weighting, which ought properly to be called adulteration, begins to be reckoned in percentage above par. In modern practice the loading consists almost exclusively of phosphate of tin with tannin: of which the silk can take up as much as 500 per cent. above par. The international standard for measuring the number, size, or fineness of silk thread is the "denier," that is, 0·05 gram per 500 metres length of thread, equivalent to 25 grains per mile. In order to give it a rustling sound (*griffe*), the scoured silk is glossed (*avivée*) with a dilute solution of acetic acid in connection with the dyeing process. By treating the rustling silk with an emulsion of sulphuric acid and olive oil in

water, the rustle can be taken out of it, and it is rendered soft; it cannot then regain its rustle. In the Author's experiments the highest tensile strength of natural silk is 53·2 kg. per mm.^{2} (33·8 tons per square inch) when dry, and 46·7 kg. (29·7 tons) when wet; the dry specimens were dried at 160° F. before testing. These figures are not surpassed by any other kind of textile fabric. By scouring and glossing raw French silk its strength was reduced to 25·5 and 13·6 kg. per mm.^{2} (16·2 and 8·6 tons per square inch) when dry and wet respectively; while loading up to 140 per cent. above par brought the strength down still lower, to 7·9 and 6·3 kg. (5 and 4 tons) dry and wet. At the same time the silk thread is deteriorated by the loading. Under the action of light the phosphate of tin employed as loading is reduced; and free phosphoric acid is gradually liberated, which attacks the textile fibre, and renders it brittle and fragile.

By the advent of artificial silk, made from nitro-cellulose or from fresh cellulose or from gelatine, the disadvantages attending the adulteration of natural silk can be largely obviated. Its strength when dry may be taken at about 16 kg. per mm.^{2} (10 tons per square inch). Tissues woven with artificial silk for the weft and with natural silk for the warp are found in practice to be far more durable than even superfine fabrics woven wholly of natural silk. After two or three years of almost daily use, such composite tissues show scarcely any signs of wear, while they are not accompanied by any of the inconveniences attending ordinary goods made of natural silk. When wet, artificial silk has only about 25 per cent. of its strength when dry, whereas in natural

Elasticity and Tensile Strength of Natural and Artificial Silk Thread.

	Description of Thread.		Specific Gravity.	Size or Fineness.	Loading above par.	Elasticity in length of 20 ins. Dry.	Elasticity in length of 20 ins. Wet.	Tensile Strength per sq. in. Dry.	Tensile Strength per sq. in. Wet.
			Sp. G.	Deniers.	Per cent.	Ins.	Ins.	Tons.	Tons.
Natural Silk.	Chinese, not glossed		1·381	19	..	3·64	5·82	33·8	29·7
	French	Raw	do.	26	..	..	..	32·1	26·0
	French	Scoured and glossed	do.	23·5	..	0·86	1·34	16·2	8·6
	French	Dyed red do.	do.	94	65	1·65	5·38	12·7	9·9
	French	Blue-black do.	do.	69	110	2·16	3·03	7·7	5·2
	French	Black do.	do.	115	140	1·73	2·22	5·0	4·0
Artificial Silk.	From Nitro-cellulose	Chardonnet, not dyed	1·51	90	..	0·88	1·04	9·3	1·1
	From Nitro-cellulose	Lehner do.	1·485	145	..	1·52	1·52	10·8	2·7
	From Nitro-cellulose	Strehlenert do.	1·489	88	..	1·64	1·00	10·1	2·3
	From fresh Cellulose	Pauly do.	1·5	..	..	..	..	12·2	2·0
	From fresh Cellulose	Cross & Stearn, Viscose Silk do.	1·489	107	..	2·20	1·84	7·2	2·2
	From fresh Cellulose	Newest Viscose Silk	1·489	107	..	2·28	..	13·4	..
	Gelatine Silk, Millar		1·37	..	..	..	..	4·2	0·0
Cotton Yarn, not dyed			1·42	70	..	1·16	1·48	7·3	11·8

silk the ratio of wet to dry is about 80 per cent. Cotton is 61 per cent. stronger wet than dry, owing to its shrinking when wet. But articles made of artificial silk suffer no material injury through the diminution of strength under wetting; and even the latter can be obviated by making them as strong when wet as such goods now are when dry. Artificial silk will then replace linen and cotton alike; and countries not producing cotton will be enabled to render themselves independent of the importation of cotton, through the daily increasing development of the artificial silk industry.

The accompanying Table[1] (p. 420) is abridged from the Author's, most of whose additional figures can be deduced from those here given.

A. B.

Properties of Artificial Silk. J. Westergren.

(Teknisk Tidskrift, Stockholm, 23 November, 1901, pp. 109-113.)

The first suggestion to produce artificially a silky texture is met with in 1734 in the writings of the eminent entomologist Réaumur; a century and a half later it was realized in practice. Externally the likeness of the different kinds of artificial silk to natural is perplexing, except in respect of their higher gloss, which at once attracts attention and is not seldom somewhat glassy. The peculiarities of the several makes are described in detail, and are illustrated by microscopic views and cross sections of the threads, magnified 150 times. The descriptions include:—Chardonnet collodion silk manufactured in France at Près de Vaux near Besançon and at Fismes near Reims, and in England at the Chardonnet factory now erected at Wolston near Coventry; Lehner silk from Glattbrugg near Zürich; Pauly silk from Oberbruch near Aix; Millar gelatine silk from Glasgow; Vivier silk; viscose silk from Kew; and Strehlenert silk.

Natural silk of all kinds is doubly refracting, and shows beautiful colours in polarized light. In artificial silk the property of double refraction depends on the raw material; gelatine silk does not possess it. The varying transverse sections of the threads, in connection with their double refraction, give rise to differences of colours and shades, by which the several kinds of artificial silk are distinguished, and which are described and explained in detail.

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[1] The names given in the Table are those of Count Hilaire de Chardonnet, inventor of collodion silk, the pioneer of artificial silks, whose French works are at Près de Vaux near Besançon and at Fismes near Reims, and English works at Wolston near Coventry; Dr. F. Lehner, whose works for the manufacture of "lustra-cellulose" are at Glattbrugg near Zürich; Dr. Hermann Pauly, Gladbach; Charles Frederick Cross and Co., and Charles Henry Stearn, having works at Kew for manufacturing "viscose," a solution of a sulphocarbonate of cellulose; Adam Millar, Glasgow, inventor of gelatine silk.—A. B.

In their chemical reactions, and under microscopic examination, artificial silks are wholly unlike natural silk. Among themselves they agree well, with the exception of gelatine silk. The effects are described of treating them with a solution of diphenylamin in concentrated sulphuric acid, and also with water, hydrochloric acid, nitric acid, potash lye, and with heating.

Air-dried artificial silk, when further dried at 110° C. or 230° F., loses from 9·2 to 14 per cent. of its weight, while in Italian raw silk the loss is 8·3 per cent. The strength is not impaired by the drying heat. The specimens so dried, being then exposed to a damp atmosphere, absorb moisture in direct proportion to what they contained in their air-dried state. These changes are also found to be related to the swelling of the threads in water, and to their strength when damp.

Natural silk when burnt leaves a glassy cinder, which requires persistent burning to reduce it to a white ash. Chardonnet and Lehner silk are easily burnt to a pure white ash. Pauly silk leaves a yellow brown ash, amounting to less than 0·1 per cent. and showing traces of iron. Other artificial silks leave more ash, from 1·0 to 1·6 per cent.; while of natural silks Chinese leaves 0·95 per cent. and tussur 1·65 per cent. These two natural silks contain between 16 and 17 per cent. of nitrogen; the various artificial silks contain less than 0·2 per cent. The latter percentage is so insignificant that in any silk fabrics the percentage of nitrogen might advantageously be taken as a measure of the quantity of natural silk they contain.

A. B.

Modern Experiments on Radiation and Absorption.

C. Schaefer.

(Zeitschrift des Vereines deutscher Ingenieure, 1902, p. 17.)

This Paper is the first of a series in which it is proposed to present the more modern views and results in the domain of physical science, especially with a view to their bearing on engineering. The Author first discusses the general laws governing the emissivity and absorptive powers of bodies, showing how Kirchhoff's law was extended to all radiations and not confined to heat rays. As the ratio of the emissivity to the absorptive power for all substances is equal to the emissivity of the absolutely black body, and as Boltzmann showed that Stefan's law—that the total emission of a body increased as the fourth power of the absolute temperature—was only strictly true for the absolutely black body, the importance of realizing in practice this ideal body was very great. The Author traces the steps by which Lummer and Pringsheim were enabled to obtain emissions which were exactly the same in their nature and intensity as if they proceeded from an

absolutely black body. The radiations are those in reality of any pencil of rays in a closed space impermeable to all radiations. The Author describes the practical construction of the apparatus, with the aid of which, and on the basis of Kirchhoff's law, proof was obtained of Stefan's law and of the two laws of Wien, one concerning the distribution of energy in the spectrum, and the other that the maximum energy increases as the fifth power of the absolute temperature. The Author gives Tables and diagrams illustrating the results of the investigation. From the diagrams it appears that as the temperature rises the maximum energy is shifted towards the shorter wave lengths. As light radiations have wave lengths of 0·4 mikron 0·8 mikron (mikron = 0·001 millimetre) it appears that high temperatures are favourable to efficient lighting. As vision is not a purely physical process, but physiological, Wien's law does not necessarily hold for light intensity, so far as the human eye is concerned; instead of increasing as the fifth power, at a temperature between 2,000° C. and 3,000° C., the intensity of light varies as the fourteenth power. From this it follows that, if the temperature of an electric glow-lamp could be raised from 2,000° C. to 3,000° C., the power required by a 16 candle-power lamp would be, not 3 watts, but only one hundredth part of a watt.

The Author also discusses the application of the laws mentioned and of other investigations, to the measurement of extremely high temperatures.

J. G.

Mechanical Installation in the modern Office Building.

CHARLES G. DARRACH.

(Transactions of the American Society of Civil Engineeers, vol. xlviii., 1902, pp. 1-71.)

As the microcosm of a great city, a modern building containing extensive ranges of offices needs careful provision for the interests and convenience of every individual occupant. It should be independent of everything apart from itself, excepting only water supply and drainage disposal. The necessary requirements are classified by the Author, who is a Member of the American Society of Civil Engineers, under headings which may be stated as follows:—1, warming and ventilation; 2, lighting; 3, water supply and drainage; 4, fire protection and watchmen; 5, lifts; 6, telephone and telegraph. All but one-eighth of the Paper is equally divided between the first and the fifth of these six headings; they are the two with which mechanical engineering is the most extensively concerned.

Steam, the source of power almost invariably adopted, can be utilized for warming, after doing its work in the engine. For both purposes together the maximum boiler-power required per

million cubic feet of space is about 140 to 200 HP., with one extra boiler in reserve. In the United States 70° F. is the standard temperature maintained during the warming period, which in New York and Philadelphia lasts from 1 September to 15 May. In winter the outside temperature sometimes falls below zero F.; and winds occur of 25 to 45 miles per hour. The greatest loss of heat is by leakage through window frames and sashes; and most of it is prevented by tight frames and good weather-strips. A saving of from 25 to 30 per cent. in coal burnt for warming was observed after weather-strips had been fitted upon a building not so protected previously. Loss by radiation during wind must be made up either by hotter steam in the warming apparatus or by larger warming surface. Even with a large exposed surface of glass, the exhaust steam generally suffices for three-quarters of the warming period; live steam is required only during very cold and windy days, and at night, and in the early morning before the building is occupied. Offices in the basement and first floor are usually warmed by a plenum of hot air. Above the first floor all halls and offices are warmed by direct radiators under the windows.

For ventilation, the radiators under the windows are each supplied with fresh air from the outside through a tortuous duct from an opening under the window sill; and the stale air is drawn away through flues between the windows by suction fans in the attic. Corridors, whether warmed similarly or by hot air from propeller fans in the basement, are kept fresh by exhausting the stale air through the lavatories and out through the closet seats, with a stronger draught than for the offices. The radiator damper is sometimes arranged for taking air in alternatively from the outside or from the room itself, or partly from both. When the outside air is entirely excluded, heat is saved at night or while the office is unoccupied. A plenum hot-air supply for the entire building is expensive, difficult to control, and in each room depends upon the temperature of the room itself, to the neglect of the ventilation. Steam of low pressure can be equally distributed to all the radiators through small pipes, by supplying it from both basement and attic; particulars are given of the sizes of the steam pipes, and of the drip pipes for the water of condensation. On this plan of double supply to radiators which expose collectively 15,000 square feet of surface, it has been found that, with steam varying from 190° to 227° in the radiators, the temperature in the most distant radiator was not more than 3° below that of the initial steam in the boiler room, when the outside temperature was 7° F.

The best and cheapest mode of lighting artificially is by electricity. The standard 16 candle-power incandescent lamp is used in offices and corridors. High and large corridors or offices are frequently lighted with enclosed arc-lamps. In corridors one 16 c.-p. lamp suffices for 800 to 1,000 cubic feet of space, or 80 to 100 square feet of floor area. Well-lighted offices have one 16 c.-p. lamp for 30 to 35 square feet. Including engine and boiler room, the Author has found that the average maximum amount of

current used varies from 50 to 60 per cent. of the total current provided for. Direct current at 110 volts is distributed on the two-wire system. The voltage is now being doubled to 220 volts, which is more convenient for electric-motors, and reduces the cost of wiring. One I.HP. is ample for every ten or twelve 16 c.-p. lamps. This power, without the aid of an electric storage battery, suffices also for all other requirements except the lifts. Three units—each comprising steam-engine and electric generator, and each rated for half the maximum power, so that one unit is always in reserve—can be worked with economy during twelve to fifteen hours; and an additional small unit should be provided for lighting at night in the engine and boiler room, and for the watchman service throughout the building.

In most buildings all water has to be pumped either direct into the service pipes or into tanks in the attic: except the supply to the boilers in the basement and to the lower storeys, which can be drawn direct from the street mains. Hot and cold water are laid on to all the washing basins in the lavatories, and to all the slop sinks for the attendants cleaning the building; the quantity so consumed per day per square foot of floor area is about 0·2 gallon. For flushing the water closets, etc., about 0·4 gallon is used; and for the refrigerating apparatus about 0·2 gallon. All floors above the level of the street sewers drain direct into them; the drainage from those below is raised into them by pneumatic pressure. The latter part of the work has been carried out by the Author, in less room and at lower cost, by using an ordinary pump driven by an electric motor, in connection with a small cesspool.

Apart from being built as nearly fire-proof as possible, office buildings are provided on every floor with portable chemical fire-extinguishers, and also with fire-hose and nozzles, and with electric signals to the engine-room. Water under pressure is supplied from the attic tanks and from a fire-pump in the engine-room.

Lifts are the source of more anxiety than any other department of the building. Their speed and size and the mode of working them must be determined beforehand, in relation to the floor area and to the height of the several storeys above the ground. In tall buildings with more than four lifts, some should stop at all floors, and others should run past the lower floors without stopping, and stop at the upper only. Four tables are given, containing data and calculations concerning the six to ten lifts in three buildings in New York of sixteen to twenty-five storeys, and the four to ten lifts in five buildings in Philadelphia of ten to eighteen storeys. Including stops, the speeds are estimated to average from 80 to 200 feet per minute, or 0·91 to 2·27 miles per hour. Electric lifts are worked by a motor, which drives either a drum whereon winds a hoisting rope, or a screw whereon travels a nut connected with multiplying sheaves and ropes. Hydraulic lifts are worked by water pressure, either from an open tank in the attic, or from a closed tank wherein the pressure is intensified by compressed air, or from an accumulator. The lift cage is either carried on the top

of a vertical ram, or suspended by ropes from overhead pulleys; the ropes are hoisted by multiplying sheaves worked by hydraulic cylinders. The water is pumped either by steam or by electricity. The lifts are counterbalanced so as to descend by their own weight at the required speed. Among details noticed are automatic safety-clutches, doors of lift and of lift-well, mechanism for starting and stopping, and signalling. An electric lift using power in proportion to the load is more economical than a hydraulic lift using as much power for light as for heavy loads. When an electric lift is worked by the same current as the lamps, the large current required at starting makes the lamps fluctuate. This defect remedied, both lighting and power can be supplied by electricity from the same generators.

Economy in working requires that continuous measurements should be made of fuel and water consumption, and records be kept of power generated and utilized. A repairing shop is essential, equipped with tools, materials, and duplicate parts, for enabling ordinary repairs to be done by the staff. The entire establishment must be under the management of a trained engineer, himself a competent mechanic.

Discussion.—Mr. Robert C. Clarkson, after twelve years' residence in the Drexel building, Philadelphia, having ventilation for every room, has just completed a year's residence in the unventilated Stephen Girard building, also in Philadelphia. Though the ventilation in the former was not particularly noticeable, its absence in the latter is extremely so. Ventilation and warming should be independent of each other, so as to avoid the expense of having to ventilate at all times, whether the building is occupied or not. Lavatories should be ventilated separately from the rest of the building. The maximum load upon the electric machinery should average 85 per cent. of the total power provided. Drainage from below the sewer level can be more readily carried out, with less risk of stoppage, by the direct use of compressed air for ejecting the contents of a closed receptacle. For protection against fire, automatic hose-reels, which by their revolution open the water valve, are not recommended; more damage can result from the uncontrolled water than can be done by the fire during the few seconds occupied in opening the valve by hand. For the same reason sprinklers are also unadvisable. Lifts must be considered as tramcars running vertically, and capable of stopping at every 12 feet. For facility of loading and unloading, the cage should have double gates, and a desired stop should be signalled two or more storeys beforehand. The gates should be fitted with mechanism to prevent the lift from being started until they are closed and locked. The area of the cage should be not less than $5 \times 5\frac{1}{2}$ feet, and the maximum speed should not exceed 500 feet per minute. The vertical hydraulic ram, carrying the cage on the top, is available for a height of 200 feet, and a speed up to 600 feet per minute. It combines safety with economy, and occupies the least space. Where steam is supplanted by electricity, an

electrically-driven pump supplying a hydraulic lift combines the economy of electric power with the simplicity of the hydraulic cylinder.

Mr. John W. Hill considers the factors involved in warming by steam include—the cubic space, the exposed surface of dead walls and of glazed apertures, the heights of the ceilings, and the construction of the dead walls, whether solid or containing air spaces. Light-wells and lift-wells acting as upcast ventilating shafts, and leakages round doors and windows, unite in withdrawing warm air from the building, thereby enhancing the cost of warming; but the increased ventilation thus occasioned is an advantage to the occupants. Indirect warming, by admitting fresh external air to the steam-heated radiators and exhausting the breathed air through ventilating flues, produces frequent change of air, but is usually the most expensive in fuel. Its cost doubtless militates against its more extensive use. In working the lifts, with loads ranging within a few seconds between empty and full, economy of power cannot be expected; but storage batteries, water tanks, or air vessels tend towards economy, although not adapted for rapidly handling heavy loads that are quickly repeated. Hydraulic lifts, arranged to consume water in proportion to load and travel, should involve the least loss of power. Electric lifts utilizing power approximately in proportion to load and travel are economical in this respect. As electricity is needed for lighting, enough should be generated in the building itself for all purposes to which it can be applied. Apart from engineering considerations, certain financial features of modern office-buildings are also dealt with at some length.

Mr. William Copeland Furber comments upon the architectural and structural requirements for office buildings.

Mr. Reginald Pelham Bolton[1] adduces examples to show that the boiler-power required depends upon the outside surface of the building, and bears no relation to its cubic contents, because in most office-buildings the interior air is stagnant. After remarks upon chimneys, he expresses the opinion that during the warming season the external temperature in New York averages 36° F.; but it is better to provide for its falling as low as zero. Not less than 60 miles an hour should be taken for the wind's highest speed. Tighter windows are needed than are yet made. It is rarely that the basement and lower storeys are warmed by a plenum of hot air. Radiators placed under the windows and supplied with outside air have not his approval. The overhead or Chicago plan of distributing steam from aloft to the radiators through a single pipe has been used by himself. Where such an overhead steam-supply from the top storey can be arranged, the distributing pipes to the radiators need be no larger than recommended by the Author; and the addition of a lower supply from

[1] See Minutes of Proceedings Inst. C.E., 1900, vol. cxliii. pp. 213–258.

the basement is then unnecessary and undesirable. Where, however, owing to the difficulty of getting an attic provided, a supply from below is adopted, steam pipes only half an inch in diameter are preferable for the bottom storeys, while even 2-inch pipes would be insufficient for supplying steam to the top storeys of a high building. A current of 220 volts has been found by himself to be not so suitable for lighting as one of 110 to 120 volts. Whereas ordinary single-cylinder engines often use 45 to 50 lbs. of steam per I.HP. per hour, a compound non-condensing engine requires only 24 lbs. The proper load to put upon the machinery should not exceed the maximum for which it is designed; and if the whole power be supplied by a sufficient number of units of suitable size, so many or so few of them may under all conditions be used as will suffice by working at their economical load to furnish the power required at the time. In a building using 77,000 gallons of water per day he arranged that the warm water from the refrigerating apparatus was pumped into a pressure drum, whence it passed through heating coils up to the general warm-water supply for the lavatories; the plan has worked admirably. The boiler feed-water can be economically heated up to about 100° by passing it through a coil immersed in the tank containing the drips from the engines. For flushing closets 0·4 gallon per day per square foot of floor area is rather too much; self-flushing urinals are most wasteful, but are required by the regulations of New York. The water supply is now commonly pumped direct into the service pipes, without tanks in the roof. In 1896 he arranged a double-pressure plan, pumping under a lower pressure to supply the lower storeys, and under a higher to the upper; this has proved economical. The extinction of fires with water is becoming antiquated. More damage is often done by the water than by the fire itself. Chemical extinguishers are recommended as far preferable. That some method is needed of proportioning the lift service to the requirements of the building, he agrees with the Author; and he gives instances of the want of adequate provision in this particular. The speed of lifts running at 700 feet per minute has had to be reduced to 600 feet, because the public objected to anything higher; many object strongly to any speed exceeding about 450 feet per minute, especially in descending. Although theoretically an electric lift might use power in proportion to the load, yet in practice the load on a lift is a succession of jumps, as illustrated by a diagram showing how at intervals of five seconds the current required for working three electric lifts together fluctuated between zero and 750 amperes. A set of indicator diagrams, taken at intervals of one minute from the engine driving the generator, shows how the power varied between 54 and 154 HP. A diagram taken from a 17 × 16-inch single-cylinder engine, at a time when four electric lifts started together, works out to more than 250 HP. Hence the difficulty of getting machinery strong enough to stand such work, and the impossibility of getting any real economy out of the engine under

such varying loads. The practical result is that to drive a number of electric lifts direct by engine and generator is not economical, and cannot be so. In the R. G. Dun building, where a maximum current of 1,600 amperes was reduced to an average ranging between 320 and 340 by placing a storage battery in parallel with the generators, the battery itself cost nearly £6,000: so that interest and depreciation preclude any idea of superior economy over hydraulic power for doing the same work. Again and again has the attempt to work electric lifts in conjunction with electric lighting proved a failure; it can succeed only with the addition of a storage battery. While presenting clear advantages for transmitting power to a distance, electricity is essentially unsuited and unnecessary for working intermittent machinery, such as lifts, placed as these are in close proximity to the source of power. Pumps driven by electricity for working hydraulic lifts have proved undesirable on any large scale. Hydraulic lifts are not so uneconomical nor so complicated when the double-pressure plan is used, which has now been working successfully for four years and a half in the Bowling Green building, New York. There a triple-expansion engine pumps all the water for the lifts, but only to 120 lbs. per square inch, which pressure suffices for the average loads; a second compound engine draws at 120 lbs. and pumps up to 210 lbs. pressure. Both pressures are led to the main valve of each lift, and the travel of the valve is arranged so that the higher pressure can be admitted after the lower. The hydraulic cylinders, instead of being 15½ inches in diameter, are only 12¼ inches, and with the lower pressure the lifts are capable of working at their proper speed under the average load, which obtains during three-quarters of the whole time; for any greater load the higher pressure is admitted by a further travel of the valve. Even though a hydraulic lift uses the same quantity of water whether empty or fully loaded, yet with lighter loads it runs faster, enabling it to make a greater number of round trips in the time; and the mileage so gained has to be considered an advantage. In the hydraulic direct-acting ram-lift the water consumption for the same work is from 30 to 40 per cent. less than in the geared hoisting arrangement.

Mr. Charles G. Darrach in reply confirms, both by theoretical calculation and by observations from actual examples, his opinion that the total boiler-power required for furnishing both power and heat depends directly upon the cubic contents of the building; and the only other factors affecting it, apart from wind storms, are the extent of glass surface and the area of outside surface exposed to the external temperature. From his experience in Philadelphia one HP. suffices for 7,000 to 5,000 cubic feet, with additional boilers in reserve. Diagrams are added of observations corroborating this proportion. A number of facts are adduced in evidence of the advantage attending a double supply of steam to the radiators, from a main feeder in the attic as well as from one in the basement. Additional examples are quoted in confirmation

of the opinion that for warming the building the main reliance must be upon tight windows. Chimneys should be designed for the most severe conditions likely to arise. With the high chimneys existing in most office buildings, water-tube boilers having 11 square feet of heating surface per horse-power can readily be worked during periods of maximum demand at from 30 to 40 per cent. above the power for which they are intended. Many details are dealt with concerning the steam supply to radiators, and the warming arrangements in general. In this relation, as well as for various other purposes, the advantages of attics are pointed out. In Philadelphia there is no difficulty in getting attics provided. The experience gained in Philadelphia with the practical use of an electric current of 220 volts has been so satisfactory as to warrant the further adoption of this voltage in preference to 110 volts. The average maximum current used for lighting has never in his experience exceeded 75 per cent. of the total current provided for. He suggests the sizes desirable for the engines, whether single-cylinder or compound, intended for driving the electric generators. In contrast with Mr. Bolton's indicator diagrams illustrating the variations in the power exerted by an engine driving an electric generator for working three electric lifts together, he shows indicator diagrams from the high-pressure cylinder of one of two compound steam-pumps for working ten hydraulic lifts; the variations in load were here much greater than those in working the electric lifts without the intervention of a storage battery. He also shows, by a diagram constructed from actual tests, that the economical range of efficiency for a steam engine is from 40 or 50 per cent. under-load to 50 per cent. over-load. Within this range a compound non-condensing engine will consume per hour from 23 to 24 lbs. of steam per indicated HP. and 25 lbs. per brake HP.; whereas a compound steam-pump, like those just mentioned, is found to require from 24 to 26 lbs. per indicated HP. and 30 lbs. or more per brake HP. Thus there is advantage and economy in employing an engine to drive a generator for working electric lifts, instead of to pump water for working hydraulic lifts. Electric lifts are already so constructed that the starting current is not more than 25 per cent. in excess of that required when in motion; and by suitably modifying the mechanism it can be reduced even lower. Finding that a set of three hydraulic lifts, with pumps worked by electric motors and without storage battery, would cost as much as the same number of screw electric lifts, with a storage battery costing £3,600, the Author adopted the latter plan, which has now been working for two years and a half. The space occupied by the storage-battery is less than would have been required for the hydraulic pressure and exhaust tanks. One screw, though made of too soft metal, will probably last still another year, and the other two at least two years more. The electrical connections and contacts have given no trouble. Repairs will compare favourably with those of any hydraulic lifts yielding a high duty. During a period of thirty days the average power was found to be

from 3½ to 4 kilowatt-hours per cage-mile; if 25 per cent. be added for losses, it is 5 kilowatt-hours or 6·7 horse-power-hours, say 7·4 brake horse-power-hours, equivalent with a compound engine to 20 lbs. of coal per cage-mile. With a hydraulic lift running light, advantage cannot be taken of increased speed, because the lift would then run faster than can be allowed; 600 feet per minute should not be exceeded, and 500 feet would give more general satisfaction. Lifts with less than 25 square feet of floor area are not desirable, and little is gained by exceeding 30 square feet. The counterbalance should never work in the lift-well. The lift should not be able to ascend without the direct application of power. The regulation in Philadelphia that the well doors shall be closed by the starting lever of the lift is worse than wrong; they should be closed by a device independent of the starting mechanism. The requirement that an air-cushion should be provided at the bottom of the well, of a depth not less than one-sixth of the height of the lift, must be regarded as a precaution against improper design, poor construction, and negligent supervision; in a lift about 500 feet high, costing itself only £2,000, the air-cushion was more than 80 feet deep, and cost £5,000. A variety of other points are dealt with, concerning storage batteries, storage tanks, saving of water in lavatories, utilization of warm condensing water from refrigerating apparatus and of waste heat in drip tank, watchman service, and precaution against fire. The last of these is treated at some length; and the Author mentions that during a recent fire in Philadelphia the provision made in the Stephen Girard building not only saved the building itself from great loss, but also afforded such help to the city fire-brigade in extinguishing the outside fire as to call forth public praise.

A. B.

Public Competition for Instrument to Measure Wind Pressure.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1902, p. 19.)

The German Ministry of Public Works has offered prizes of the aggregate value of £500 for the best three designs for an instrument to measure the pressure of the wind. The technical conditions are: (1) The instrument must be able to measure the mean force of the wind acting on surfaces and bodies of various forms, so that the results of the observations may be applicable to statical calculations of strength. The suction on the lee side of surfaces exposed to the wind must also be shown by the instrument. It is considered desirable that, in addition to the magnitude of the force of the wind, the point of action of the resultant should also be indicated. The varying values of the pressure must be shown as the ordinates of a curve the abscissas of which are to a scale of time.

Apparatus by which the amount of pressure is obtained indirectly—from the velocity of the wind—will not be considered as complying with the conditions.

The competitor whose instrument, after extensive trials, is found most suitable for use in Government departments, will receive a further premium of money and other advantages.

The contributors to the prize fund are the Government departments of Public Works, the Navy, War, Trade and Industry, the Prussian Steam Boiler Users' Association, and the Association of German Engineers.

J. G.

Coal Conveyors at Edinburgh Electricity Works.

(Electrician, vol. xlviii., 13 December, 1901, pp. 291–292.)

The coal-conveying plant here described is installed in the McDonald Road Works, Edinburgh, and was erected by the New Conveyor Company, of Smethwick. Small coal is shovelled from railway trucks into a concrete pit, 136 feet long, 14 feet wide, and 10 feet deep. It is then fed automatically into elevators, which have their boots sunk 7 feet 6 inches below the bottom of the pit. The elevators have 16-inch buckets, attached at 2-feet pitch, to the lifting chains, the whole being enclosed in cases inclined at an angle of 60° to the horizontal, the said cases being of ironwork, 66 feet long, and 3 feet by 2 feet in section. Each elevator rises 30 tons an hour, and they deliver together into one hopper. Thence the coal is taken by two 18-inch cross-conveyors across the boiler-house, which contains two rows of boilers, facing each other. It is then delivered through shoots into the middle of either of two longitudinal conveyors, each 12 inches wide by 130 feet long, which run respectively over the fronts of the two rows of boilers, the cross-conveyors being 17 feet 6 inches, and the longitudinal ones 9 feet 6 inches above the level of the floor of the coal store. The longitudinal conveyors deposit the coal along the overhead stores in sunk steel hoppers, which connect by means of measuring chambers and guide shoots with the stoker hoppers. The coal store is 20 feet above the firing-floor level, and contains 20 steel hoppers (one corresponding to each boiler), 11 feet by 4 feet, by 4 feet 6 inches deep. The whole is worked by enclosed motors, nine in number, each of 6¾ HP. The article contains three drawings, which show the plan, cross-section and longitudinal section of the arrangement. The ashes are also automatically removed by other conveyors, which are fully described.

W. H. S.

100-*Mile Car Test.*

(Horseless Age, vol. viii., 1901, pp. 77–82.)

The following are the results of an independent trial. The highest award was obtained by the "Gasmobile" and "Haynes-Apperson" cars.

LONG ISLAND AUTOMOBILE HILL-CLIMBING AND ENDURANCE TEST, 20 APRIL, 1901.

Make of Vehicle.	Horse-Power of Motor.	Number of Passengers	Corrected Time. 100 Miles. Hrs.	Mins.	Secs.	Number of Stops.	Total Time of Stops. Mins.	Secs.	Per Cent. of Efficiency.	Time. Mins.	Secs.	—
De Dion-Bouton .	5	2	6	58	0	1	9	0	98·2	1	48	Winner in class below 1,000 lbs.
De Dion-Bouton .	5	2	..			..	..		..	3	34	Did not finish the course.
De Dion-Bouton .	5	2	..			..	..		..	..		Did not reach hill.
Darracq . . .	6	2	7	50	30	5	9	30	98·1	3	30	
De Dion-Bouton .	5	2	..			..	..		..	1	40	Did not finish course.
"Packard" . .	9	2	7	58	30	4	41	30	91·7	5	50	
"Gasmobile" . .	9	2	6	56	0	None	None		100·0	3	35	
"Gasmobile" . .	9	2	..			..	..		..	2	35	Did not finish course.
Daimler (Delivery)	6	4	10	40	0	4	18	0	96·4	..		Exact time not taken at top of hill.
De Dion-Bouton .	10	2	..			..	..		..	20	25	Did not finish course.
Electric Vehicle Co.	5	3	7	26	0	11	12	0	97·6	3	50	Winner in class between 1,000 and 2,000 lbs.
"Gasmobile" . .	9	2	5	34	0	3	20	0	96·0	11	25	Disqualified.
"Gasmobile" . .	9	2	5	53	0	1	0	15	99·9	2	39	Disqualified.
Haynes-Apperson .	8	4	7	11	0	None	None		100·0	4	30	
"Holyoke" . .	9	2	6	41	0	1	1	0	99·8	2	10	Winner in class above 2,000 lbs.

M. O. G.

Brick Chimneys for Power Stations. W. D. Ennis.

(American Electrician, vol. xiii., December, 1901, pp. 570–572.)

The proportions of a chimney are determined with reference to the quality of fuel and amount to be burnt per hour, type and dimensions of furnace, boiler and setting, arrangement and size of flues, average and extreme limits of temperature of the external air, elevation above sea-level, variation of atmospheric humidity, and limiting dimensions of the chimney itself. The basis on which evaporation is calculated is that of taking a boiler-HP. as equivalent to 34½ lbs. water evaporated per hour at 212° F. and atmospheric pressure, and assuming that 6·9 lbs. of water are evaporated per lb. of coal. The consumption of steam in lbs. per I.HP. per hour may be assumed at: 17½ lbs. for compound condensing engines; 23½ lbs. for simple condensing engines; 30 lbs. for simple non-condensing engines; 40 to 70 lbs. for uneconomical throttling or slide-valve engines, and 100 lbs. for direct-acting simple steam pumps. For a central power station of average size a good brick chimney will cost complete, in the neighbourhood of New York, about $15 per 1,000 bricks. The number of bricks per HP. varies with the economy of the design. One chimney built for 8,000 boiler-HP., 10 feet diameter, 225 high, with independent inner core, contained 700,000 bricks above the ground line. Another, 5 feet 6 inches inside diameter, 125 feet high, contained 230,000 bricks. One built for 3,000 boiler-HP. contained 450,000 bricks. Another (without inner core) of octagonal shape, with a round shaft, 10 feet in diameter and 125 feet high, had 165,000 bricks. All these are exclusive of concrete foundations. The function of an inner core is to increase the efficiency of the draught by retarding radiation through the chimney walls. This object is secured by the use of hollow bricks which are coming into use. The questions of costs of foundations, thickness of walls, the direction and junction of flues, and the ornamentation of chimneys are also dealt with in this paper.

F. J. R.

Working Costs of Isolated Plants. I. D. Parsons.

(Engineering Magazine, vol. iii., January and February, 1902, pp. 573–588, and pp. 721–736.)

The Author has collected a considerable amount of information in New York bearing on the expenses of working private plants, several of which were, however, on an extensive scale. The figures for seventeen such installations are given in full, together in some cases with load curves, etc. Each one of the seventeen cases is considered separately, and the circumstances in connection with each are noted. The buildings vary from a large block of offices,

twenty floors high, standing on ground 70 feet by 100 feet, having ten lifts, and 575 kilowatts of plant installed, down to a club, five floors high, standing on ground 35 feet by 100 feet, with no lifts, and 20 kilowatts installed. The cost per unit in the latter case, in which the dynamo was only run from 4 p.m. to 1 a.m., and no battery was used, was about 5*d.*, and in the former case about 2·2*d.* The original Paper should be consulted for particulars as to the results of working in the various buildings considered. The Author thinks that on the whole the statistics show the decided advantage of the isolated plant over the central station service. This is said to be more noticeable in the case of the smaller installations, seeing that they would be charged by the central station at a higher rate, and some further saving is also experienced through heating the building by exhaust steam. The question of heating is, from the American point of view, of great importance; and the Author thinks that this consideration alone to a great extent justifies the existence of isolated plants in most cases.

W. H. S.

Electric Light and Power in San Francisco.

(Journal of Electricity, San Francisco, vol. xi., December, 1901, pp. 269–279.)

A station has lately been erected by the Independent Electric Light and Power Company, and is here described. The boiler-house contains eight Babcock boilers, each of a capacity of 500 HP. The economisers are placed immediately behind the boilers, and on a higher level; there are two rows of them, and they fill out the whole of the double flues leading to the chimney, the steam-pipes passing over the top of the flue to the engine-room. The chimney is opposite the middle of the boiler-house, two flues leading into it from both sides; it is 10 feet in diameter, and 125 feet high, being constructed of steel and lined with fire-brick. The engine-room plant includes four 1,500-kilowatts and one 500-kilowatts two-phase generators, giving their output at 500 volts and 60 cycles and 116 revolutions per minute; also two 100-kilowatts exciters, and nine 750-kilowatts step-up transformers, by which the two-phase current is changed to three-phase at 11,000 volts. It is transmitted to various sub-stations, whence it is supplied to the consumer either as direct current on the three-wire system at 110, 220, or 440 volts, or as two-phase alternating current at 115, 230, 440, or 2,300 volts, the sub-stations containing the necessary transforming machinery. The main station, above described, is at Potrero; the power is transmitted by overhead lines for a distance of 4 miles, to a point which appears to be on the outskirts of San Francisco; after this point the high-tension transmission line is placed below the ground. Some of the sub-stations are described, and a further article is to deal with the distributing system more fully. Drawings are repro-

duced, showing plan, cross-section, and longitudinal section of the main generating station, and there are several good process blocks.

W. H. S.

The Waterside Station of the New York Edison Company.

(Electrical World and Engineer, vol. xxxix., 4 January, pp. 5–14; 11 January, 65–76; January 18, 111–116; and February 1, 1902, pp. 191–194.)

The new power station of the Edison Company is here described which generates high-tension alternate current, and transmits it to the numerous sub-stations, which is converted by rotaries and fed as direct current into the low-tension three-wire network. The Waterside station will generate the bulk of the current used on the system, and some of the already existing stations will supplement it when required, all of them being, however, used as distributing sub-stations. The Waterside station stands on ground 272 feet by 197 feet, facing the East River, the foundations being on bed rock. The boiler-house is 76 feet by 267 feet 10 inches, and the engine-room is 115 feet by 267 feet 10 inches. There are two electric cranes, having capacities respectively of 25 and 50 tons. Coal is received at a pier built out into the river, and by means of conveyors and elevators it is discharged into the bunkers, which are built over the boilers, and store 10,000 tons, or two weeks' supply. There are 56 boilers, arranged in two rows on two floors; reckoning 12 lbs. of steam per I.HP-hour, they will each develop 1,625 HP. without forced draught. They were constructed by Aultman and Taylor, and are of the water-tube type. They will work at 170 lbs. pressure, and are fitted with Roney stokers, forced draught being furnished by fan blowers. The stokers and most of the rest of the auxiliary apparatus are steam-driven. There are four steel stacks, each 17 feet in diameter and 200 feet high; they are lined with firebrick for one-third of their height, the remainder being lined with red brick. The lining is carried on rings of angle iron, and an air space of 4 inches is left between the lining and the stack. Steam is delivered into a 14-inch ring, to which sixteen connections are made from the boiler-house, the boilers being also connected together by pipes which are independent of the ring. All joints are ground to a steam-tight fit, and no gaskets are allowed in any of the high-pressure piping. The condensing water is brought from the river through an intake tunnel, composed of two ¼-inch steel shells, with a space of 15 inches between them filled with concrete. Just before the intake tunnel enters the building it is divided into two parts, each 7 feet in diameter, one running under each row of engines; the water is discharged to the river through two tunnels of oval shape 8 feet high. The engines are by the Westinghouse Machine Company, and are sixteen in number; they are of the marine type, vertical, with one high-

and two low-pressure cylinders; cylinders $43\frac{1}{2}$ inches and $75\frac{1}{2}$ inches diameter, stroke 5 feet. The low-pressure cylinders only are jacketed, as superheated steam will be used; they run at seventy-five revolutions per minute, are capable of giving 10,000 HP. with a cut-off at $\frac{5}{8}$ths of the stroke, and are guaranteed to give their most economical load of 5,500 HP., with a consumption of $12\frac{1}{2}$ lbs. of steam per I.HP.-hour. The shaft has a diameter of 26 inches; the cranks are set at angles of 101°, 133°, and 126°; and the flywheel has a diameter of 23 feet, and weighs 90,000 lbs. To facilitate synchronising, the speed can be varied from the switchboard by operating a motor, which shifts the weight on the governor arm. Each engine has a Wheeler surface condenser with cooling surface of 9,200 square feet. The sixteen three-phase General Electric generators give their outputs at 6,600 volts and 25 cycles, the revolving field weighs 130,000 lbs., the armature 125,000 lbs., and the foundation plates 20,000 lbs. There are three exciter sets, each consisting of a 6,600-volt induction motor coupled to a 150-kilowatt direct-current machine. A battery is also provided, able to excite the fields of all the generators for 1 hour. The arrangements of the switchboards, switches, bus-bars, etc., are fully described, everything being mounted in fireproof compartments, built up out of brick and soap-stone. A large number of drawings and photos illustrate the various devices. High-tension cables are connected to all the sub-stations; the number of feeders taken to each was based on their known loads, the maximum drop not to exceed 5 per cent., and the maximum carrying capacity for continuous load to be 250 amperes per phase. The standard copper section was therefore fixed at 250,000 circ. mils. for each of the three conductors. The company now owns 41 miles of rubber cables, for their high-tension work. The new cables are insulated with paper; each cable contains three conductors of 37 strands, and each conductor has a sectional area of 250,000 circ. mils. when each wire is laid out straight. The paper insulation is $\frac{5}{32}$ inch around each conductor, and $\frac{5}{32}$ inch for the outer insulating jacket; the lead covering is $\frac{1}{8}$ inch in thickness, and contains from 2 to 3 per cent. of tin. The test pressure is 15,000 volts alternating current for 1 hour, and the insulation resistance, when laid in the subways and jointed up, is not less than 300 megohms per mile. There are now sixteen rotary converter sub-stations on Manhattan Island. The rotaries are six-phase and of two sizes, viz., 1,000 and 500 kilowatts rated capacity. The former give 270-volt direct current at 187 revolutions per minute, and the latter by means of induction regulators give their output at any voltage between 240 and 360. Storage batteries are used in nearly all the sub-stations. The standard battery contains 150 cells, and has a capacity of 400 amperes for ten hours. For low-tension feeders a lead-covered, paper-insulated, two-conductor concentric cable is used, each conductor having a section of 1,000,000 circ. mils. the whole being provided with six pressure wires. The conductors have $\frac{5}{32}$-inch paper insulation, and $\frac{9}{64}$-inch lead jacket. The distributors

are either 350,000 or 200,000 circ. mils. single conductors, with $\frac{4}{32}$-inch paper insulation and $\frac{4}{32}$-inch lead jacket. They are designed for a maximum working pressure of 750 volts direct current. The articles contain a large number of drawings, particularly in connection with the switchboards and switches. They also include a plan and cross-section of the generating station.

W. H. S.

Salford Electricity Works.

(Engineering, vol. lxxii., 13 December and 27 December, 1901, pp. 803–807 and 864–866.)

This station supplies continuous current for lighting and traction at the usual pressures. The boiler-house, 221 feet by 55 feet 9 inches, contains sixteen Lancashire boilers, 30 feet by 9 feet, fitted with mechanical stokers and superheaters. Each pair of boilers is directly connected to one engine, besides being connected to the 14-inch steam main, which has three copper expansion bends, each bend consisting of two 10-inch copper pipes. There are two chimneys, one at each end of the boiler-house, and two economisers, each containing 800 tubes. The engine-room, which is 221 feet by 44 feet, contains eight 775-kilowatt dynamos, giving their output as compound-wound machines at 525 volts, or as shunt machines at 480 volts; they run at 100 revolutions per minute. The compound engines are of the three-crank vertical tandem type by Browett, Lindley & Co., and are described in some detail; the generators have an efficiency of 95 per cent., weigh 50 tons, are connected to flywheels weighing 18 tons, and were built by Mather and Platt. There are also three balancers, each consisting of two 25-kilowatt dynamos running at 600 revolutions per minute. The travelling crane lifts 30 tons. Coal is lifted by cranes out of the barges, being delivered in boxes holding 2 tons fitted with collapsible bottoms, and tipped direct into the bunkers, which hold in all 1,600 tons, and are placed immediately above the boiler fronts. Clinker and ashes are removed by an ash conveyor, the arrangements in connection with which are fully described and illustrated by drawings. The article contains drawings showing the plan and cross-section of the boiler- and engine-rooms, the general design of the engines, the arrangement of ash-conveying plant, and several showing the connections on the various switchboards.

W. H. S.

Salford Tramways.

(Tramway Railway World, vol. x., December, 1901, pp. 692–699.)

The track is laid with rails, weighing 103 lbs. per yard, delivered in lengths of 60 feet, and manufactured by the Leeds Steel Works. The specification for the composition of the steel was as follows: Carbon not less than 0·5 per cent., silicon not more than 0·06 per cent., phosphorus not more than 0·08 per cent., and sulphur not more than 0·06 per cent. A drawing shows a section of the rail, fishplates, soleplate, and bolts. The trolley wire is of 0000 B. & S. gauge.

W. H. S.

Bermondsey Electricity Works.

(Electrician, vol. xlviii., 17 January, 1902, pp. 489–493.)

This station is worked in connection with a dust destructor, which is made up of six cells, and consumes 50 tons per day. Forced draught is applied to the furnaces, the pressure being created by fans; steam-jets are also fitted. The destructor gases pass through the three Babcock boilers, which evaporate 6,000 lbs. of water per hour; thence they pass through duplicate flues to the chimney, which is 150 feet high. The feed-water is softened in the Stanhope apparatus, and is stored in a tank, holding 10,000 gallons. The engine-room contains one 75-kilowatt and two 150-kilowatt continuous-current sets, which are at present non-condensing, and exhaust into the chimney. The balancers deal with an out-of-balance current of 50 amperes, the crane lifts 10 tons, and the cells discharge at the rate of 300 amperes for one hour. The feeders are triple concentric cables of 0·25 square inch section, the distributors are of 0·1 square inch section, and the arc light lines consist of twin conductor, 0·023 square inch section. There are 70 double-carbon arc lamps, burning thirty-two hours. A plan and cross-section of the generating station are given.

W. H. S.

Electric Power Transmission in Mexico. E. Pinson.

(Génie Civil, vol. xxxix., 12 October, 1901, pp. 377–383.)

This paper contains a description of the installation for the transmission of power to Mexico City, from Villada and Fernandez-Leal on the Rio de Mote-Alto, a distance of 35 kilometres, and from Alameda, Chiluca and Madin on the Rio de Tlalnepantla, a distance

of 26 kilometres. The alternators are driven by turbines and give current at 440 volts two-phase, which is transformed to 22,000 volts three-phase for transmission. Details are given of the lines with diagrams.

H. R. C.

The Zossen Marienfelde Polyphase Railway Trials.

W. Reichel.

(Zeitschrift des Vereines deutscher Ingenieure, vol. xlv., 28 September, pp. 1369–1377; 5 October, pp. 1414–1419; and 12 October, 1901, pp. 1457–1463.) See also Electrical World and Engineer for 7 September, 5, 12, 19, and 26 October, and 2 and 9 November, 1901.

These articles contain a description of the experimental trials which have been made by Siemens and Halske on the polyphase railway between Zossen and Marienfelde, a distance of 14¼ miles, with grades ranging up to 1 in 184, and a minimum radius of curvature of 3,280 feet. Experiments were first carried out with a view of determining the effect of wind pressure, as the formulas in ordinary use give figures which are much too high in the case of speeds exceeding 62 miles an hour. An apparatus constructed on the principle of the anemometer, and driven by an electromotor capable of giving 200 HP. for short periods, was therefore made. The arms were about 10 feet 6 inches long, and at the ends of the arms the bodies to be rotated were attached. After some preliminary trials, a body having its front and back ends of a more or less paraboloidal shape was used, the air resistance being then found to be only about one-third of that opposing a flat-ended one. It was finally determined that to propel a car with its end shaped in this manner, and estimated to weigh 94·5 metric, or about 93 British, tons, when carrying the full complement of 50 passengers at the rate of 125 miles an hour, would require 1,000 HP. The Author gives figures showing the way in which the weight is distributed between the various electrical and mechanical portions of the car. Several drawings are given showing the construction of the car and of the trucks for the same. The car is 24 yards in length, the body being carried on longitudinal girders joined together by top and bottom plates formed of U and flat iron connected by heavy iron sheets reaching from the lower edge of the car-body to the lower ends of the windows. There are two six-wheeled trucks, and the car-body is attached to each truck frame by means of a projecting pin, without the intervention of springs. The truck frames themselves rest primarily upon adjustable spiral springs, from which the load is transferred to long flat springs which rest on the journal boxes. The wheels are 49 inches in diameter, and the motors are mounted direct on the two outer axles, the middle one in each truck being left free to provide space for the supporting frame for the pin in the car-body, and for the braking apparatus. A Westinghouse automatic brake is employed, braking the wheels on

both sides. A hand attachment is provided, by which the motorman can apply about 80 per cent. of the brake power. The transformers transform from 10,000 volts to 1,150 volts, though the pressure available at starting is 1,850 volts. Each truck has two motors, there being, therefore, four in all for the car, each furnishing normally only 250 HP., though capable of an output of 750 HP. in order to obtain sufficiently rapid acceleration. Metallic resistances are used for regulating the speeds; to facilitate cooling these are enclosed in flat cases, placed along the two side walls of the car. In order to make the connections between the resistances and the controllers as short as possible, the controllers are also distributed along the sides of the car, and are operated by compressed-air mechanism, which is also employed for working the switches. The variation of the voltage obtained from the transformers is effected by varying the connections from star to delta. Each of the two transformers has its three legs laid flat in the direction of the length of the car; in this way it is possible to set up circulating air-currents for cooling. The primaries are permanently connected in star fashion. The connections between the switches and transformers consist of bare wire mounted on high-pressure insulators. The air-pumps are placed beneath the motorman's platform, and are operated by current supplied by special small transformers. The electrical equipment really forms two distinct units, each one containing two motors, two rheostats, two main switches, two fuses, one large transformer with delta and star switches in the secondary, and primary high-pressure switches, as well as a high-pressure protective device, an air-pump and small transformer with fuses, a trolley, an air-reservoir, and a motorman equipment with compressed-air switches and measuring instruments. In case of one equipment being disabled, the pressure in the primary circuit of the motors will be raised.

Motors.—The motors have six poles, and a normal speed of about 900 revolutions per minute. The stator core is undivided, owing to the numerous connections which would be required if it were made in two halves. The case is of steel, and, to facilitate cooling, is made smooth inside and closely fitted to the stator core, both it and the bearing covers being made in two parts to admit of removal for repairs. To the lugs of the lower bearing covers flat iron pieces are bolted, which transmit the turning moment of the motor to the truck by means of springs. No further spring attachment is employed, as it was considered likely to lead to trouble at the higher speeds contemplated. As the heating of the core is mainly in the primary, large radial depth was required to ensure low saturation. To economise space without sacrifice of turning moment the primary was therefore made the rotor, the current being led to it through eight carbon brushes and three collector rings. The rotor winding is of the continuous-current bar type, which enables wire bands to be employed to provide against the high centrifugal tension.

Controller.—The starting rheostat is divided into twenty-nine steps, four primarily to cut in the motor, and the other twenty-five for the

gradual variation of its speed, each step cutting out 20 HP., the motor output being 750 HP. at starting and 250 HP. at full speed. This can be effected without serious sparking. For each phase of each motor there is one of the flat cases previously referred to, 3·47 feet in length, containing the four starting coils, and another 5·12 feet in length, for the other twenty-five coils, the height and width of each being 4 feet and 5·8 inches respectively. They are of angle iron, bolted to the top and bottom car girders, with sheet-iron, shutter like, ventilated covers. The coils are of "Kruppine," of 1·75 inch by 0·078 inch section, supported on porcelain insulators, the lower attachments being so made as to allow of expansion. For each phase of each motor there is a controller cylinder parallel to the length of the car and beneath the large cases. The contact-pieces are of bronze and removable, the *a*, *b*, *c* connection being employed to avoid the necessity of twenty-five regulating contacts for each phase. On the first contact the four motors are cut in succession instead of simultaneously, which saves resistance material, besides throwing the load on to the station more gradually. The controller is actuated by a differential arrangement consisting of a pair of large and small oppositely acting air cylinders, the smaller one always being under pressure. This gives very complete control to the motorman without taxing his strength. *Switches and Fuses.*—To divide the current and to enable a damaged motor to be cut out, each motor has its own mean-pressure switch, and a safety fuse for each phase. The switch has a double break of 5·4 inches in each phase, the six contacts being set in a circle with the actuating air-cylinder in the centre. A snatch-hook comes into action when the switch is closed, and, when breaking, maintains contact until the air-piston has reached its lowest position, thus giving a quick break. The arc is drawn in a narrow insulating tube, and extinguished by a metal cooling ring. The transformer switches, as well as those for the motors, are built for both delta and star connections, one transformer switch being provided for each connection for each unit of the equipment, so that there are eight switches in all for the four motors. The high-pressure fuses are enclosed in four tubes contained in one large tube of mica. The high-pressure switches differ from the mean-pressure ones in being arranged in sets of three, one-half of the switch being below, and the other half above the roof of the car. The compressed-air arrangement by which they are operated is of the same general character as for the mean-pressure switches. *Compressed-air Mechanism.*—The air-tanks for the brakes and the switches are located respectively in a corner of the floor of the platforms at each end of the car, and on the ceilings above them, a pressure of 8 atmospheres being employed for the brakes, and 4½ atmospheres for the switches. The tanks at each end of the car are connected by two equalising pipes, and the system is operated from a table on the front of the platform. *Current Collection.*—The trolleys are of the bow type. It was considered inadvisable to allow any crossing over the line, both because the wires might be touched from the bridges,

and because they would necessitate the lowering of the trolleys, which would be undesirable at such high speeds. This decision gave the designers unlimited space above the roof. The trolley pole is formed of two telescoped Mannesmann tubes 7·8 inches in diameter, the lower one being firmly fastened to the floor of the car, and passing through a sleeve bearing in the roof. By means of a hand-brake operating a double set of gears the mast can be revolved by the motorman, and it can be held in its lower bearing by a wedge. At the upper end of the lower tube is a cast-steel flange, surrounded by a hard rubber sleeve, and to this flange the tube carrying the collector rings is attached. Three contact springs press against these rings as shown, and are attached to hard rubber posts carried by an iron support fixed to the roof of the car. The upper tube is fitted into the hard rubber sleeve on the lower one, and fixed by screws. The trolleys are carried by the three revolving sleeves 1 metre, or 3·28 feet, apart on this tube. The enormous wind pressure is prevented from causing the trolleys to leave the wire, both by means of springs and by the use of equalising plates, the wind pressure on which opposes that on the trolley. The collectors are detachable, and of steel tubing as usual. The trolleys are electrically connected to bronze cups carried on the bell insulators above the axes of the trolleys. From them the current passes by contact springs, through lightning arresters of the ordinary fork type, to the collector rings. There are two trolley poles on each car in order to divide the 200-ampere current. *The Trolley Line.*—The trolley wires are carried on wooden poles 35 metres apart, and 2¼ metres, or 7·38 feet, from the centre of the track; they are 1 metre apart, with the lowest wire 5½ metres, or 18 feet, above the surface of the rails. The wires are doubly insulated, each insulation alone being capable of withstanding a pressure of 12,000 volts. One of these is the hard rubber chain at the top and bottom of the bow-shaped iron support which carries the three trolley wires. The second consists of a conical iron bolt about 200 millimetres, or 7·8 inches, in length, surrounded by a hard rubber sleeve 5 to 6 millimetres, or about 0·2 inch, in thickness. The insulator, also of rubber, is screwed into a thread about 2 inches long at the upper end of the sleeve. The wires are of hard-drawn copper with a section of 100 millimetres, or 15 square inches, and a conductivity of 97 per cent. of that of chemically pure copper. The 23 kilometres, or 14·26 miles, of line are divided into sections of 1 kilometre, and each section is anchored in the direction of its length. The sections are connected by easily removable wires in the place of section switches. Between any two sections the trolleys leave the wires for a distance of about 10 millimetres, or nearly 33 feet, but as the two battery poles are 17·64 millimetres, or nearly 58 feet apart, the car is never without current. In case of a broken wire the current-carrying wire will be grounded. At each point of support of the trolley wires is clamped a loop of 8 millimetres copper wire, which, if the break occurs in the wire, will be pulled against a copper wire, which terminates above in a

spring, while its lower end is attached to the rails. Copper cable rail bonds are employed. The rails are connected by a wire to the neutral point, and are earthed by ground plates at intervals of a kilometre. The feeders are of bare wire where possible, with a section of 50 square millimetres. Where cables have to be used the section is 70 square millimetres.

The paper contains a detailed description of the preliminary tests of the electrical equipment. The Author calls attention to the fact that it is impossible for the motorman to come into contact with any of the wires, even the insulated ones.

G. W. DE T.

Croydon Electric Tramways.

(Electrician, vol. xlvii., 4 October, 1901, pp. 899–902.)

The energy is supplied by the Corporation at the rate of 2*d*. per Board of Trade unit to the British Electric Traction Company, who have a lease for the undertaking. When completed the total length will be, expressed as single track, 17½ miles. The chief interest is in connection with the Quin system of protection, which is being installed throughout. It primarily consists of an automatic maximum and minimum cut-out in each section of the line. These sections are separated by the usual insulators. From the negative bus-bar in the Quin pillar, a shunt is taken to the far end of the trolley wire, and connected to it at the sectional insulator. The current through this shunt coil keeps the automatic switch closed, but should the trolley wire break, or the current fail, the switch which connects the feeder to the trolley wire opens, and the section is completely isolated. If a telegraph or telephone wire comes in contact with the trolley wire there is further protection; a series coil is placed between the feeder and the trolley wire, and this acts on the switch, disconnecting the circuit should an excess of current flow through it. The Corporation plant consists of 300-kilowatt Belliss-Thomson-Houston sets. A third set of 600 kilowatts is to be added.

W. W. H. G.

New Bedford and Onset Street Railway.

(Street Railway Review, vol. xi., December, 1901, pp. 879–887.)

This line is about 23 miles long, and is supplied with power from stations at Wareham and New Bedford, which are near the respective ends of the line. The Wareham station contains a 300-kilowatt and a 200-kilowatt generator, both belt-driven; also a 250-kilowatt direct-coupled unit. The new Bedford power-house has more modern plant, consisting of two direct-coupled 800-kilowatt machines running at 100 revolutions per minute; there are in ad-

dition two older belt-driven machines. The generators are wound for 750 volts, but current is generally supplied at about 650 volts, for which pressure the motors are wound. The track is mainly constructed of 70-lb. rails in 60-foot lengths, placed on chestnut ties spaced 20 inches centre to centre; Crown bonds are used, and Weber rail joints. The trolley wire is No. 00 gauge, and is supported partly by brackets and partly by span wires, wooden poles being used in the country, and iron poles in the towns. The article contains several drawings, showing the plan of the station at Wareham, some of the piping arrangements, and a cross-section and a plan of the car-shed at Wareham. The car-sheds are protected by sprinklers in the roof, and by sprinkler pipes under the floor between the pits for fire-insurance purposes, and the pits are heated by steam pipes.

W. H. S.

Brighton Tramways.

(Tram. Rly. World, vol. x., December, 1901, pp. 700-704.)

A plan is given showing the routes that are opened; there are 6½ miles in all, mostly double track. The rail used is 6 inches deep, and 7 inches across the base; weight not stated. They are in 36-foot lengths, with a small proportion of 30 feet. A drawing shows a section of the rail and fish-plates; and another drawing shows the construction of the joints, in which a 6-inch steel girder transverse sleeper is laid under the sole-plate, and, crossing the track, connects together the rails on either side; bolts pass through the base of the rail, the sole-plate and the top flange of the sleeper. The transverse sleeper is buried in the concrete, which is 12 inches deep at these points; over the rest of the track, the concrete is 6 inches deep under wood paving of American red gum. The trolley wire is of No. 000 gauge. The tramway power-house adjoins the lighting station, and contains one 325-kilowatt and two 175-kilowatt machines.

W. H. S.

The Milan-Monza Tramway. G. Semenza.

(Street Railway Journal, vol. xviii., December, 1901, pp. 515–518.)

The line is 10½ miles long, including 2 miles of city track, belonging to the Milan tramways. From the centre of Milan to the city boundary at Loreto, the track is laid with 93-lb. girder rail; the rest of the track is laid with 53-lb. Vignoles rail. The rail bonds consist of two copper wires brazed to the foot of the rail. The brazing is done by making a coil at the end of the bond, and using a hand-blower. The Author says that an experience of four years in Milan shows that the bonds are thoroughly good, and

electrolytic corrosion is so far unknown. Two No. 00 trolley wires constitute the overhead conductors. The line is supplied with power at its middle point from the Paderno-Milan transmission system. Eighteen bare copper wires of No. 00 gauge convey current at 42 cycles and 15,000 volts into the sub-station, where the pressure is reduced by transformers to 330 volts, and then transmitted to two rotary converters of 200-kilowatt capacity. The periodicity has been found to be rather high for the satisfactory working of rotary converters. There is also a battery of 280 cells, having an output of 800 amperes for one hour; the positive plates are of the Majert type, and the negative plates of the Pescetto type. The article contains a drawing showing a section and plan of the converter station, and also a section of the car used on the line.

W. H. S.

Nogent Tramways. T. Pausert.

(Écl. Électr., vol. xxx., 25 January, 1902, pp. 133–143.)

The earlier portions of these tramways, dating from 1887, were worked by compressed air, but this system was not found to lend itself to further extensions, and was abandoned in favour of electric working. The system at present consists of 50 kilometres of lines serving twenty communes in the vicinity of Paris, with a line running into the city as far as Place de la Republique. The power-house is at Vincennes, and contains eight multi-tubular boilers having a heating surface of 106 square metres each, and suitable for a pressure of 17 atmospheres. They are capable of evaporating 2,500 kilograms of steam per hour each. Reducing valves are employed to reduce the pressure to 8 or 9 atmospheres for the engines. Town water is used for feeding the boilers, and is softened by means of a "Desrumeaux" softener. A deep well is also provided as a stand-by. The engine-room contains two 500-kilowatt generators and two of 325 kilowatts. The 500-kilowatt generators are driven by compound Corliss engines, having 600 and 950-millimetre cylinders with 1,080 millimetres stroke, running at 95 revolutions per minute, and the smaller ones by single-cylinder engines. The engines exhaust either to the atmosphere or into jet condensers, the water being passed into a cooling tower and used again. The generators are over-compounded to give 500 volts on open circuit and 600 volts at full load. A set of three negative boosters, driven by a 15-kilowatt motor, are employed for the return cables. The switchboard is provided with two positive bus-bars, allowing different feeders to be supplied at different pressures. The feeders, of 300 and 400 square millimetre section respectively, are lead-covered and armoured, and are buried directly in the ground. The trolley wires, 9 millimetres in diameter, are suspended 7 metres above the ground, and are divided into sections of 1,500 metres connected through switches. They are carried by brackets on steel poles. The track

is laid to standard gauge of 1·44 metre. The rails are partly of the "Broca" section, weighing 48 kilograms per metre with Falk cast-welded joints laid on concrete, and partly of the "Vignoles" section, weighing 25 kilograms per metre, laid on wooden cross sleepers and doubly bonded with "Chicago" bonds. For a length of 3 kilometres in the suburbs of Paris, the trolley is discontinued, and the cars fed on the side-slot system already in use on the other Parisian lines, while in the city itself the cars are driven by accumulators. The cars for the city measure 11·25 metres overall and carry 78 passengers. They have roof seats with a canopy. They are mounted on bogies of 1·22 metre, wheel base spaced 3·87 metres from centre to centre. Each car carries two motors of 45 HP. The battery consists of 210 cells weighing 18 kilograms each, and is charged in about nineteen minutes from the trolley wire. For the suburban service the cars are without accumulators, and carry 52 passengers. They are mounted on four-wheel trucks and carry two motors of 35 HP. Air and hand-brakes are used. At Maltournée, 8 kilometres from the power-house, there is a 400-ampere-hour buffer battery provided with a booster for charging.

A. E. L.

Hamburg Tramways. H. Vellguth.

(Street Railway Journal, vol. xix., January, 1902, pp. 1–12.)

A complete description of these tramways is here given. The track is laid with 106-lb. girder rails; the groove is $1\frac{1}{4}$ inch in width and depth, the inner flange is $\frac{9}{16}$ inch wide, and the head of the rail is $2\frac{3}{8}$ inches wide, the base being $5\frac{1}{8}$ inches across, and the depth of the rail 6 inches. The construction is unusual in many ways, noticeably in that no cross-ties of the usual kind are used, but the rails are joined together by a flat rod of peculiar section, which embraces the rail bases by means of extensions, and is secured by wedges. The fishplates are also of special section, and are carried round beneath the base of the rail on both sides. All these features are illustrated by drawings, which also show the standard track construction in streets with and without concrete foundation. It was found that the treads of the wheel-tires wore more rapidly than the flanges; the expedient was therefore adopted of having the outer rails with grooves $\frac{9}{32}$ inch deep on all curves having radius of less than 33 yards. At these points the outer wheels therefore run on the flanges, and no case has occurred where a car has jumped the rails. Even now the wear on flanges and treads is not equalised, and it is intended to adopt the shallow-grooved rails on the outers of all curves having a radius of less than 80 yards. These shallow rails are also used on built-up crossings. On curves where the shallow-grooved rails are used the gauge is made somewhat tighter, the rule being to make it 1,432 millimetres instead of 1,435 millimetres. The rails are double-

bonded with copper bond wire 0·35 inch in diameter. More than half the track is laid on a ballast of coarse gravel on broken stone, of which the latter is preferred. Concrete foundations have only been used where the entire street had such a foundation, and then a layer of asphalt $\frac{13}{16}$ inch in thickness is placed between the rail and the concrete. The switch tongues, which are of Siemens-Martin steel, are 13 feet long and operated by hand. The trolley poles of Mannesmann steel are 40 yards apart. On one of the main streets some double-bracket poles are used, though they appear to be placed at the side of the road which borders the harbour. These brackets are 28 feet long, and, being of ornamental design, the poles are said to have cost £500 each. The trolley wire is No. 0 in the suburbs and No. 000 with a figure 8 section in the town. Recently a wire having a rectangular section, but rounded at the corners, has been introduced. The thickness of this wire is $\frac{5}{16}$ inch, and the cross-section is 158,000 circ. mils. The tension on a No. 0 trolley wire is 400 kilograms; when the warm weather approaches small pieces are cut out of the trolley wire at convenient points, and these are replaced in colder weather. The trolley wires on the streets with heavy traffic are replaced every three years. Power is purchased from the town electric lighting company, which owns all the connecting cables, and is said to be responsible for any damages due to electrolysis. There are in all 33 feeding-points. The rolling stock is also described, and the passenger receipts analysed. W. H. S.

Chicago and Joliet Interurban Railway. A. S. KIBBE.

(Street Railway Review, vol. xii., January, 1902, pp. 4–13. See also West. Electn., vol. xxix., 5 October, 1901, pp. 218–219.)

This line consists of 70 miles of single track, with no grades exceeding 5 per cent., and few sharp curves. The rails vary from 40 to 73 lbs., being chiefly 70 lbs. per yard, and are bonded with one "Protected" bond equivalent to a No. 0000 wire at each joint. Most of the track is laid on the highways, on cross-ties, ballasted with limestone 6 inches deep below them, and paved in towns. Span construction is used wherever possible. The trolley wire is No. 000; the feeders are of aluminium cable, part working at 15,000 volts, part at 2,300, and the remainder at 600. The only difficulty with the aluminium cables has lain in their high coefficient of expansion. The generating plant at Joliet consists of two G. E. alternators of 750 kilowatts each at 60 cycles per second, 2,300 volts, driven by 12 turbines operated by the River Desplaines. The nearest sub-station (1 mile) is fed at 2,300 volts; two others, at 12 and 24 miles respectively, are fed with current transformed up to 15,000 volts. On account of the high frequency, induction-motor generators are used in the sub-stations in preference to rotary converters, which are unstable under these conditions. In

the distant sub-stations the current is stepped down to 550 volts for the motors. Large storage batteries have been installed at the sub-stations to obtain the best results from the water-power, and the fluctuation of the motor-generator loads is only about 10 per cent. Motor-driven boosters with compound winding are used to charge and discharge the batteries. Commodious buildings have been provided to house the plant. Cars 20 and 30 feet long are used for local services. For interurban traffic, the cars are 36 feet long, on Brill trucks. The wheel base is 6 feet, and the gauge standard. Christensen air-brakes are fitted. Each car is equipped with G. E. 67 motors geared to 40 m.p.h. Normally the cars, which weigh 50,000 lbs. loaded, make the 30-mile run in 80 minutes, including twenty or thirty stops, and use 75 to 90 units. The traffic arrangements are described, and the article is fully illustrated.

A. H. A.

Rail Feeder Construction in San Francisco. S. L. Foster.

(Street Railway Journal, vol. xix., January 1902, pp. 25–26.)

The main station is situated on a street having a double tramway line on it, constructed of 62-lb. girder rails. Exclusive of the current brought back by the earth, which consisted mainly of a bonded 20-inch cast-iron salt-water pipe, and an unbonded 30-inch similar pipe, all the current was brought back to the power-house along the double-track road, the joints being bonded with three No. 000 bonds. The rails were connected to the negative bar by four copper bars, each of 1,000,000 circ. mils. section. As the load increased in the process of time from 1,200 kilowatts to 5,000 kilowatts, the loss in rails and cables became excessive. About 300 yards north and south of the power-house there are two points where the traffic becomes congested, and though the total section of the return paths from these points amounts to about 160 square inches of steel, or about 16 square inches of copper, the maximum current of 10,000 amperes was very uneconomically carried. The copper cables, too, became extremely hot, and at times the sleeve connections were partially unsoldered; at times of heavy load they were only saved by the chilling effect of streams of compressed air. Moreover, alleged electrolytic destruction of lead service pipe occurred near the station. It was, therefore, determined to increase the capacity of the return conductor on the street facing the power-house. For this purpose a nest of fourteen old 45-lb. steel tramway rails was laid in a trench along this street for about 600 yards, connecting the points above mentioned, and where this line of rails passed the power-house it was connected to the negative bar by two copper conductors 1 inch by 5 inches in section. The successive rails of each were connected by a riveted lap-joint 12 inches long, the joint being also bonded by two copper tubes, $1\frac{5}{8}$ inch in outside, and $\frac{5}{8}$ inch inside diameter. The 1 inch by 5 inches copper bars were

10 feet long, and were connected together by lap-joints 7 inches long, and held by eight ⅝-inch steel bolts. Further details of the construction and of the method of making the various connections are given at length, accompanied by drawings. The current density in the return conductors has now been reduced to a maximum of 500 amperes per square inch. Careful tests were carried out before and after the alterations were made, and it has been found that there is a saving in the power required amounting to 2¼ per cent. of the total output of the station. The results were to some extent improved by the fact that after the old rails were connected up, the fishplates and bonds were removed from the double track passing the power-house, and the joints were cast-welded. The average C^2R loss in the return conductors is stated to be only 21·3 per cent. of its previous value, and the estimated saving per annum amounts to 78 per cent. of the total cost of the work.

W. H. S.

Surface-Contact Railways at Wolverhampton.

(Tramway Railway World, vol. xi., February 1902, pp. 65–76.)

These tramways have been equipped on the Lorain system. At present 1 mile of track is open for traffic, but the remaining 10 miles will be opened in the course of the next few months. The cost of track construction has been about £5,500 per mile, and in addition the cost of the surface-contact system has been about £1,800 per mile, making a total of £7,300. The gauge is 3 feet 6 inches, and the rails weigh 100 lbs. per yard, a drawing being given showing their section. The insulated cable, which is of 0·05 square inch section, is brought up through the concrete at intervals of 10 feet, this being the distance between the various contact boxes. The cables are laid on the solid system in bitumen; but ordinarily the Lorain Company is said to prefer a drawing-in system. The contact box consists of a base of insulating material, known as reconstructed granite, and a metallic cover, the main portion of which is of iron, and the central part at the top is of specially hardened non-magnetic steel, adapted to resist the wear of the collecting shoe. The contact is made between two carbon surfaces in a hermetically sealed chamber, the rising contact being connected to the feeding cable by a thin strip of hard rolled copper about 1½ inch wide, folded upon itself. After the car has passed, the contact is broken by the force of gravity. Three drawings are given, showing sections of the contact-box. A diagram is reproduced showing the method of wiring the car, necessary for the Lorain system, and provision has been made for taking current from an overhead line, in case the cars should be run on any such section. The energizing coils for the magnet carried on the car have a compound winding, one being in series with the motors, and the other being a shunt winding of the normal tramway

voltage. Six cells are carried on the car, which are charged, when necessary, by closing a switch, which places the cells in series with the motor. The cells are used at the moment of starting the car from the car-shed. Three drawings show the arrangement of the collecting shoe and magnets on the car. Power is provided from the town electricity works, and two units of 825-kilowatt capacity have been installed for the purpose, the engines being by Willans and Robinson, and the generators by the Electric Construction Company. W. H. S.

Calculations for Electric Railways.

(Street Railway Journal, vol. xviii., December, 1901, pp. 543–546, and vol. xix., January, 1902, pp. 45–53.)

The articles in question deal with the proposed construction of a railway between New York and Port Chester, and contain a large amount of useful information. The projectors of the proposed railway are under the necessity of proving the convenience and desirability of the railway, as well as of showing that it is practicable both electrically and financially. In this case they were opposed by several existing railways, who alleged in the first instance that the figures set out were incorrect and the proposed scheme impossible; but these allegations were subsequently retracted. The figures and calculations given in the present articles may therefore be taken as being correct; and as they were prepared on an extensive scale, they are of considerable interest. The proposed railway is 21 miles long, and it is intended to run express trains, covering the distance in thirty-one minutes, allowing for ten stoppages. A large number of curves are reproduced as being part of the evidence of the promoters. The first shows the so-called speed and distance curves for a 400-ampere motor equipment, this being the size selected. From these curves it is possible to see the speed reached and the distance travelled at any time. Next follow similar curves for a 300-ampere motor equipment; but this was not found able to do the work in the allotted time. It may be added that both these curves show the results obtained on the level, and on various up and down grades up to 2 per cent. The next curve shows the effect of coasting and braking, and gives the relations between instantaneous speeds and distances covered at any moment. The full braking-power is taken as being equivalent to a retarding force of 150 lbs. per ton, producing a negative acceleration of 1·6 mile per hour per second. The differences of grade are also taken into account. Then follow two complicated sets of curves, showing the performances of 400-ampere and 300-ampere motor equipments, under varying conditions of gear ratio, allowing also for the difference between express and local trains, and giving coasting and braking curves with the distances travelled in given

times under the different circumstances. The last set of curves, nine in all, shows the variations of speed between the different stations on the line, the kilowatt-hours consumed on the various portions, the various inclines, distances, curves, etc., and in most cases these curves are plotted both for express, fast, and local traffic. All the curves are well reproduced and fully explained in the text. It is impossible to analyse them, but the following may be taken as an example of the results shown. On a run between two stations of $1\frac{5}{8}$ mile, with a train consisting of one car weighing 52 tons, the figures are as follows:—

—		Express.		Fast.		Local.	
		Mins.	Secs.	Mins.	Secs.	Mins.	Secs.
Time consumed		2	32	2	$34\frac{1}{2}$	2	54
Kilowatt-hours		13	54	11	12	6	92
Kilowatt-hours per car-mile		8	34	6	85	4	26
Watt-hours per ton-mile		160	0	131	6	81	9
Mean speed in miles per hour		38	5	37	9	34	0
Percentage	Energy	100	0	82	2	51	2
	Time	100	0	101	6	113	2
	Speed	100	0	98	4	88	3

Further, estimates of working expenses, of the cost of construction, and of the probable receipts are given in considerable detail, and there is a verbatim report of the examination of the expert witnesses. The case was evidently got up with great care, and the articles will repay examination.

W. H. S.

Range-Finders. G. Forbes.

(Society Arts Journal, vol. l., 20 December, 1901, pp. 78–86.)

A portable instrument is described and explained, suitable for use by infantry. Stereoscopic vision is employed to get over the difficulty of "spotting" the object. The aluminium base contains four pentagonal prisms, and the rays entering each end of the base pass through two of these prisms, being twice internally reflected in each before reaching the Zeiss binocular. The base is 6 feet long, and has a hinge in the middle, by means of which the instrument can be folded up, or used with one-half of the base acting as a support. The base weighs $2\frac{1}{2}$ lbs. to 3 lbs. and the binocular $2\frac{1}{2}$ lbs. When the latter has a magnifying power of 12 the Author claims an accuracy of about $\frac{1}{3}$ per cent. at 3,000 yards. In the eye-pieces there are vertical marks, one fixed and the other movable by a micrometer screw, the reading of which gives the distance required when the two marks coincide.

G. E. A.

Modern Boiler Problems. E. D. Meier.

(Power, New York, vol. xxi., December, 1901, pp. 28–29. Paper read at the meeting of the New England Cotton Manufacturers' Association, September, 1901.)

Increased demand for, and altered conditions of, steam-power have rendered departure from formerly recognised standards necessary. Furnace capacity and efficiency can no longer be confounded with boiler capacity and efficiency, just as the boiler must now be considered apart from the engine. Modern conditions include the combustion of 25 lbs. with natural, and 35 lbs. to 50 lbs. with forced, draught per square foot of grate area per hour; steam pressures of 150 lbs. to 200 lbs. per square inch and even more, and feed-water temperatures very much above the old 100° F. or 110° F. The range of qualities of fuel to be used is also much greater; even the different grades of size of good coal produce different results. Thus good bituminous produces 7·1 HP. per square foot of grate, anthracite egg 5·8 HP., pea coal 4·4 HP., buckwheat coal 3·6 HP., and rice coal 3 HP. As length of grate is limited even with mechanical stokers, width becomes the measure of power with low-grade fuels. Heating surface must be disposed to meet such a requirement. The high steam-pressures render large diameters and all collapsing stresses undesirable. Great economy demands high furnace-temperatures and ample combustion space, so that the gases are not quickly cooled by the heating surface. These and other considerations point to the suitability of water-tube boilers as compared with either internally fired or externally fired cylindrical shell boilers.

F. J. R.

"*Electro-Catalytic*" *Igniter.*

(Locomotion Automobile, vol. ix., 16 January, 1902, pp. 42–44.)

A piece of platinum-iridium, or preferably osmium-iridium-ruthenium alloy, is mounted in a tubular metal socket which screws into the combustion chamber of the engine, like an ordinary electric sparking plug. The osmium alloy is heated by an electric current of about ½ watt, and the motor turned by hand in the usual manner for starting. The hydrocarbon vapour sucked in from the carburettor then causes the igniter to glow brightly, and the ignitions commence. The electric current is then cut off, and the ignitions continue automatically until the engine is stopped by cutting off the mixture from the carburettor. The point of ignition can be varied by shifting the igniter within the tubular socket. This adjustment is easily effected by an external screw. The igniter is the invention of A. Wydts.

C. R. D'E.

Electrical Equipment of Cranes. W. Rung.

(Electrical Review, vol. xlix., 6 September, pp. 411, 412; 27 September, pp. 499, 500; 18 October, pp. 621, 622; and 29 November, 1901, pp. 903–905.)

The direct-current series-wound motor is well suited for cranes. It has great starting torque, and starts smoothly; it lifts a heavy load slowly and a light one quickly; but it is unsuitable in cases where the load is liable to be very small, as the speed may then become so high as to be dangerous. The shunt motor is mainly used in cases where a constant speed is desired. The polyphase motor is as good as a direct-current motor; its starting torque can be made as great as that of a series-wound motor, and its speed can never exceed the normal. In any case the motor must start smoothly with a small amount of current, and must stop as quickly as possible when the current is switched off. It should therefore have a small amount of inertia, and run at a low speed. In the case of a 50-HP. motor, running at 550 revolutions per minute, the armature weighed 500 kilograms, with a diameter of 36 centimetres; another motor, also of 50 HP. running at 200 revolutions per minute, had an armature weighing 800 kilograms, with a diameter of 56 centimetres. Upon calculating the moments of inertia it was found that the former required 2·9 times as much power at the start as the latter. As for three-phase motors, sizes up to 4 HP. or 5 HP. can be made with squirrel-cage rotors, and require no starting resistance, but they have relatively small starting torque, and start suddenly. Brown, Boveri & Co. build such motors with rotors of large electrical resistance; this increases the starting torque, and provides a smooth start. The brake action, caused by changing the motor into a generator, does not necessarily bring the armature to rest. If the braking is attempted after the speed has fallen below a certain limit, the electromotive force of the motor may be so small as to cause no braking action, and in any case this method does not enable the load to be held in any position. Some form of mechanical friction brake is almost always added. An iron or copper disk rotated in a magnetic field will produce a braking action owing to eddy currents, but this action ceases as soon as the speed falls below a certain limit. The positions of the motors on the crane are then discussed, and a drawing is given showing the most suitable arrangement of motors and the wiring for a three-phase crane. The motor for working the crane longitudinally is best placed at the middle of one of the girders. The other motors should be carried by the crab. Any arrangement by which a motor is placed at the end of one of the girders is undesirable, although it shortens the electrical connections. Spur-wheel gearing is to be preferred to worm-wheel gears on the ground of efficiency.

W. H. S.

Electric Feed-pumps. A. Johnston.

(Electrical Review, vol. l., January 10, 1902, pp. 43, 44.)

The main problem in connection with electric feed-pumps is the regulation of the amount of water pumped into the boilers. One method is to close, or partially close, the check valves; the pump is run at constant speed, and is fitted with a relief valve, which is set to open at 20 per cent. or 25 per cent. above the working pressure of the boiler, the surplus water being returned to the hot well. Another method is to insert a resistance in series with the motor, which reduces the voltage across the motor terminals; the current will, however, be practically constant at all speeds. Neither of these methods can be regarded as economical. The best method is probably that using the series-parallel control, the motor armature having two separate and similar windings, each connected to a separate commutator. The Author gives a list showing the various combinations possible, supposing the motor to be series-wound and the field to be divided into two equal sections. He is in favour of direct-coupled pumps without gearing, the pumps being smaller than usual, and the motors larger. In some correspondence which took place in the two succeeding issues of the *Electrical Review*, Mather and Platt state that they construct a feed-pump in which the delivery is controlled by varying the length of the stroke of the pump; and Merryweathers state that they construct a direct-connected pump, and give some figures which show the results obtained from one of their pumps erected in the Bristol electricity works.

W. H. S.

The Boston, U.S.A., Subway and the Rapid Transit Subway, New York.

(London County Council Report, No. 555, 7 November, 1901, pp. 3–19; also Tramway Railway World, vol. x., December, 1901, pp. 709–712. Abstract.)

Both these schemes were entered upon on the reports and suggestions of Commissions appointed by the local authorities in the respective towns; in the case of Boston the Commissioners visited, as a preliminary step, numerous European cities for the purpose of comparing the various methods adopted for the relief of street traffic congestion. The Boston tramway will, when complete, be equivalent to 5 miles of single track, part being laid with four tracks, and part with two. That portion now completed is 1,300 yards in length, and commences with an incline 100 yards in length, carrying the surface lines underground. In streets where ample space existed, the method of open excavation was adopted, tunnelling proper being resorted to for one or two short lengths where cut-and-cover methods were not practicable. There

are three distinct types of subway: (1) the side walls and arch are of masonry; (2) two distinct masonry tunnels side by side; (3) transverse steel girders and jack arching to form the roof, supported by side walls composed of steel columns interspersed with masonry or concrete. The open inclines leading to the tunnel have granite walls, and are protected by railings. The standard height of the roof is 14 feet clear above the surface of the rails, and the roof is generally about 3 feet below the street surface. Lifts are thus unnecessary, approach to stations being gained by a short, well-lighted stairway. The island principle has been adhered to in the platforms and separate entrances and exits provided. Glazed brick lining is used only near the stations, the remaining lengths being simply whitewashed. Both the overhead trolley and third-rail systems are employed. The tunnel is lighted throughout by incandescent lamps, although a considerable amount of natural light is obtained. The number of cars running in each direction is 250 per hour, the passenger traffic at the busiest station being stated at 27,400,000 per annum. In the opinion of the London County Council Commission the effect of the subway upon the street traffic has been very considerable.

New York.—The subway here is at present under construction, and will consist of a total length of 21 miles, seven of which are to be laid with four tracks and 14 miles with double tracks. Cut-and-cover methods are adopted, the covered way being rectangular in shape and built in open trench. Transverse steel frames supported on concrete bottoms are placed at 5-foot intervals with concrete walls and roof, the concrete enclosing the steel entirely. Light steel columns between the tracks afford a further support to the roof. The two centre tracks will be used for an express service, designed for a speed of 30 miles an hour, with stations 1½ mile apart. On the outer tracks 14 miles an hour is the designed speed, with stations at more frequent intervals. Crossings and switches are reduced to a minimum by lowering one track under the other. The work will be completed in 1904.

The London County Council Commission favour the plan of shallow underground tramways for London as a means of (1) linking up existing tramways by taking surface cars through congested and prohibited areas, (2) affording provision for pipes, cable wires, etc., thus obviating the continual breaking up of the streets. C. E. A.

System of Rail-Joints.

(Tramway Railway World, vol. x., November, 1901, pp. 624–625.)

This system is in use at Linz on the Danube, where it is employed on the electric street and mountain railway. The rail-coupling is constructed without screws, on the well-known wedge principle, and grasps the base of the rail at the joint, for which

reason it has been designated the "rail shoe." It can be used either alone or in combination with a fish-joint, and with its use it is impossible for either rail end to be depressed, the unpleasant jolting which is so injurious to the rail-ends being thus eliminated. The joint can be put down by four men with the aid of very few tools and a portable blast-furnace. Both the placing and moving can be effected with ease. It makes a reliable electrical contact, although it is not as yet recommended that the usual copper contact-pieces be dispensed with. Besides having the advantage of a low price, it is claimed that its cost is less than one-half of that involved in casting round or welding the rail. The joints form strong supports, owing to their broad bases, increasing the stability of the whole line. Explanatory diagrams are given.

C. E. A.

Wireless Telegraphy. Ferrié.

(Soc. Int. Élect., Bull., vol. ii., January, pp. 9–49; discussion, February, 1902, pp. 85–103.)

This Paper deals historically with the progress of wireless telegraphy since the year 1900, when a joint report by the Author and Blondel was presented to the International Congress of Electricians. At the conclusion of the historical sketch the Author observes that wireless telegraphy is still subject to two serious drawbacks: (1) The complexity, cost, and delicacy of the apparatus required; (2) insecurity of communication. The latter is the more important and is not remedied by syntonising. Transmission of messages between two points can be made impossible by operations carried on with that intent at a station between them; and, again, communication is often interrupted by atmospheric disturbances. The Author commits himself to the prophecy that the telegraphic efficiency will always be low on account of disturbing causes and of slowness of transmission, both of which defects he considers to be inherent. For this reason, and on account of the increasing difficulties to be apprehended from interference between different stations as the use of wireless telegraphy extends, the Author considers that its usefulness will be mainly restricted to naval purposes, though it may possibly find use in special cases in the mercantile marine and in military operations.

Discussion.—G. Claude spoke at length in favour of the theory that the action of the antennæ depended mainly on their electrostatic capacity relatively to the earth and to each other. The Author of the Paper, in his reply, showed that this theory, which had been put forward by Anderson in 1898, was inconsistent with numerous well-ascertained results of observation.

G. W. de T.

100-*Ton Testing Machine*. J. H. Wicksteed.

(Institution of Mechanical Engineers Proceedings, vol. iv., pp. 933–938; discussion, September, 1901, pp. 939–943.)

A description is given of a 100-ton universal testing machine recently built for the engineering laboratory at Glasgow University. The machine is of the horizontal type, the weighing system consisting of an L lever, and a horizontal lever with travelling poise. The chief points of interest are the readiness with which the machine can be arranged for tension, compression, shearing, bending, or torsion; a holding nut on the hydraulic ram whereby the load may be maintained on the specimen for an indefinite time, independent of any leak of water; roller stays to guide the weigh-bridge when compressing the blocks during shearing; the use of an auxiliary poise starting from the fulcrum for loads up to 32 tons, during which the larger poise ($\frac{1}{2}$ ton) is clamped at the short end of the lever; the wheels of the travelling poises are arranged to form a geometrical slide. Full diagrams are given.

H. R. C.

Determining Small Time Intervals with the Watch.

R. Etzold.

(Zeitschr. Instrumentenk. Beib., vol. i., 1 January, 1902, pp. 1–3.)

Watches are fitted with a small resonance box of wood to render the beats audible at a distance; the observer has then both hands free.

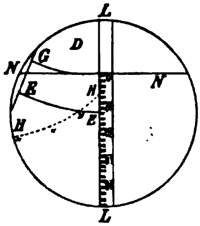
H. B.

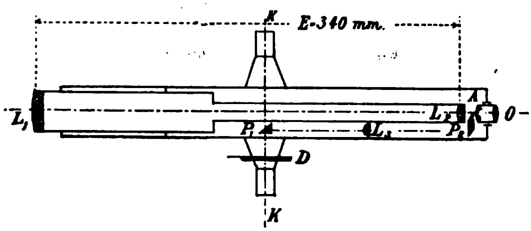
Hammer and Fennel's Tachymeter-Theodolite. E. Hammer.

(Zeitschr. Instrumentenk., vol. xxii., January, 1902, pp. 21–26.)

The instrument is used for determining horizontal distances and differences in level between itself and a vertical surveying pole, one setting only being made, and without reading an angle of altitude or making a trigonometrical calculation. Results of the first trials were published in the above journal in 1900, and the present Paper describes the working of the instrument. In Fig. 1, showing the field of view in the telescope, the lines G, EE and HH belong to a photographed diagram, LL is the image of the surveying pole, and NN the cross wire. Tilting the telescope causes the diagram image to pass across the left half of the field, the zero line G always touching NN. Taking the numbers from

the figure, the "distance" line EE cuts the pole at 0·14, and the "height" line HH cuts it at 0·08. The constants 100 and 20 reduce these numbers to—Horizontal distance = 14 metres; difference of level = 1·6 metre. Fig. 2 gives a section of the instrument.





The diagram D is fixed with its plane perpendicular to the axis KK. The two images are formed by $KP_1L_3P_2AO$ and L_1L_2O, the latter by means of the enclosed Porro telescope. The field of view is halved by the edge of the prism A. The limits, with a 4·4 metre pole, are 300 metres and 60 metres respectively.

G. E. A.

Town Refuse Disposal in Great Britain. W. F. GOODRICH.

(Cassier, vol. xxi., December, 1901, pp. 99–122.)

The Author gives a historical sketch of the introduction of destructors, beginning with Fryer's in 1876, and then describes and illustrates the Fryer destructor at Cambridge, Warner's destructor at West Hartlepool, Baker's at Clerkenwell and Lambeth, Meldrum's at Nelson, Horsfall's at Fulham, Heenan's twin-cell destructor at Blackburn, Mason's refuse gasifier, and the Beaman and Deas' destructor at Colne. The importance of the matter to any locality may fairly be judged from the fact that from 15 cwts. to 20 cwts. of refuse are produced daily by each 1,000 of the population. In some cases the evaporative value of the refuse is as high as one-fifth of that of coal, but the percentage of value differs with various kinds of refuse and different destructors, varying from one-fifth to one-fifteenth. Where the evaporative value is less than one-tenth that of coal the destructor cannot well

Town.	Evaporation per Lb. of Refuse.	Average Steam Pressure.	Temperature of Feed Water.	Consumption of Refuse per Cell per 24 Hours.	I.HP. Produced per Ton on Basis of 20 Lbs. Steam per I.HP.	Duration of Test.	Number of Cells or Grates in Use.	Rate of Combustion per Square Foot of Grate per Hour.	Boilers in Use.
		Lbs.	°F.					Lbs.	
Oldham . .	0·880	128·0	212	1 cell =7·96 tons	98·0	24 hours	10 cells	25·0	2 Lancs. 30′ × 8′
Ashton-under-Lyne . . .	0·783	122·0	212	1 „ =9·97 „	87·0	24 „	6 „	31·0	2 Multitubular
Bury . . .	0·532	..	53	1 „ =9·0 „	59·584	4 „	6 „	33·6	3 „
Rochdale . .	1·78	114·0	212	4 grates=50 T. 15 C. 1 Q. 4 Lbs.	199·0	6½ „	4 grates	54·9	1 Lanc. 30′ × 8′
Darwen . .	1·55	193·0	212	4 „ =52 2 1 6	173·6	48 „	4 „	56·0	1 „ „
Nelson. . .	1·516	118·0	212	4 „ =61 0 0 0	169·792	9½ „	4 „	57·0	1 „ „
Nelson. . .	1·85	120·0	212	4 „ =31 0 0 0	207·2	1 month	4 „	29·0	1 „ „
Nelson. . .	1·95	122·0	212	4 „ =73 4 0 0	218·4	8 hours	4 „	68·5	1 „ „
Blackburn .	1·39	90·8	212	2 „ =25 9 1 12	155·68	12 „	4 „	48·0	1 „ 24′ × 7′
Fleetwood. .	1·19	135·0	212	1 cell =21 11 2 2	133·28	8 „	2 cells	80·5	1 Babcock W. T.
St. Helens .	1·54	127·0	212	1 „ =27 12 0 8	172·48	7 hours 20 minutes	2 „	103·0	1 „ „
Warrington .	1·14	68·0	104	1 „ =23 0 0 0	127·0	24 hours	2 „	88·48	1 „ „
Blackburn .	1·297	122·3	212	1 „ =11 3 0 12	145·264	7 hours 40 minutes	4 „	34·66	2 Heenan W. T.
Liverpool . .	1·173	..	212	1 „ =16 10 0 0	131·376	24 hours.	8 „	62 16	4 Babcock W.T.

be reckoned as a power producer. In order to analyse the performance of different destructors, several Lancashire towns are selected in which the calorific value of the refuse may be presumed to be pretty uniform, and the results from these are given in the Table on p. 460.

In other Tables in this article are given full records of results of a twenty-four hours' test of the St. Domingo destructor at Liverpool, of one month's continuous work of the Meldrum destructor at Nelson, and of a test of shorter duration in which the plant was forced, without sacrifice of the general efficiency, of a test of Heenan's destructor at Blackburn, and of Beaman and Deas' destructor at Canterbury. In all these cases the fuel value of the refuse for evaporation or steam raising, and the soundness of the principles on which these British destructors have been constructed, are demonstrated.

F. J. R.

Electric Power at Ikervar, in Hungary.

(Société Belge, Élect., Bull., vol. xviii., November, 1901, pp. 383–397.)

In this article a detailed description is given of the hydraulic plant and electrical installation at Ikervar, in Hungary. The power is transmitted to Szombathely and Sopron, and is used for lighting the surrounding villages, for working two lines of tramways, and for other industrial purposes. The water-power is derived from the River Raab, a tributary stream of the Danube; the flow of water is about 22 cubic feet per second, and the total available power is over 2,000 HP. The power-house is situated about 3 kilometres from the towns of Ikervar and Sarvar. Five Jonval turbines are erected, of which each is capable of developing about 300 HP. at 160 revolutions per minute. Each turbine has coupled direct to its horizontal shaft two 6-polar direct-current Thury dynamos, the high electromotive force required being obtained by coupling a number of series-wound generators in series on the Thury system. The turbines are manufactured by Messrs. Escher-Wyss, of Zürich. The generating plant at Ikervar is divided into two distinct groups. The group A contains three turbines, each driving two dynamos of 97·5 kilowatts capacity at 1,500 volts, or a total voltage of 9,000. The Szombathely circuit is connected on to this group. The other group, B, contains two turbines, each driving two dynamos of 100 kilowatts capacity of 2,500 volts, giving a total voltage of 10,000. The Sopron circuit is provided with power from this group. At Ikervar each dynamo has its independent switchboard, and as the demand for power increases or decreases, so the number of dynamos are put on the circuit or cut out by a simple device. The power is transmitted to several sub-stations, where motor-generators are used, so as to provide current either at 150 volts for lighting purposes or at 550 volts for

the tramway working or other motive power. On the high-tension lines from Ikervar to Szombathely and Ikervar to Sopron there are a few installations connected, where the motors are put in series, and used for agricultural purposes: ploughing, threshing, tilling, grinding, etc. One of these installations consists of thirty motors, each of 10 HP. to 25 HP., coupled in series, and they work very satisfactorily. The speed of the motors is kept regular by suitable governors invented by Thury.

The Szombathely high-tension line is about 65 kilometres long, and the total loss in transmission and transformation is 27·5 per cent. The sectional area of the conductors is 70 square millimetres. A telephonic line is fixed, a metre lower than the high-pressure line, on the same posts on which the conductors are carried. The Szombathely sub-station contains two 130-HP. motors, each driving two 75-kilowatt dynamos; another motor of 110 HP. drives two 74-kilowatt dynamos. A 50-HP. motor drives a dynamo of 33 kilowatts at a voltage of 550 for the tramway line. An accumulator battery of 120 Tudor elements, with a capacity of 540 ampere-hours, is also erected there. As reserve a large steam boiler is put up, which can, in case of emergency, work a 200-HP. vertical compound engine. The three-wire system is used in the lighting circuit. There are about 8,000 lamps connected. The tramway line is 2,700 metres long; the overhead wire system is applied. The Szombathely circuit provides the current for the lighting of about twenty villages, the most important being Ikervar and Sarvar, which have their own sub-stations. The Szombathely railway station has a 130-HP. motor, driving two dynamos of 35 kilowatts output for the lighting of the station.

The Sopron line is about 150 kilometres long, and the sectional area of the conductors is 80 square millimetres. About thirty villages are supplied from this circuit. The transmission and transformation loss is 27 per cent., the drop per kilometre being 8 volts. The sub-station at Soprano contains two motors, driving each two 40-kilowatt dynamos at 150 volts, and an accumulator battery. A 130-HP. gas-engine has been erected as a reserve. For the tramway circuit there is a motor driving two 41-kilowatt dynamos, and a battery of 275 Tudor elements is provided. The tramway (a trolley line) is 5,200 metres long.

L. G.

Maidstone Electricity Works.

(Electrical Engineering, vol. xxxi., 3 January, 1902, pp. 6–10.)

The three-wire continuous-current system is employed; 230 volts each side. The steam generating plant consists of four Davey, Paxman and Co. multitubular boilers, each capable of evaporating 6,000 lbs. of water per hour. Working pressure 160 lbs. per square inch. The main steam-pipes are in duplicate, but

all valves are in the branch pipes. The feed-pumps and pipes are in duplicate. The surface condensing plant can deal with 18,000 lbs. of steam per hour. The electric generating plant comprises four 150-kilowatt dynamos and one 75-kilowatt dynamos, each coupled to a "Peache" engine, the larger sets running at 375 revolutions per minute, and the smaller at 420 revolutions per minute. The balancing and charging is done by a combined balancer and booster, consisting of four machines coupled together, the two outer ones being the boosters. The shunt regulating switches for all machines are fixed in a polished teak rail in front of the switchboard, the latter being of Messrs. Kelvin and White's make. A set of 280 chloride cells in glass boxes forms the battery, which has an output of 100 amperes for five hours, or 300 amperes for one hour. The distribution is on the Callender solid system, by the three-core pilot-cable; the arc-lighting mains and the services to the consumers are armoured with steel tape and laid direct in the ground. The feeders, of which there are six, contain only two conductors, and two neutral feeders are laid. Mains are laid in 5 miles of streets. Sizes and details are given. The load is equivalent to over 9,000 8-candle-power lamps. Details of the chimney and of the foundations, which are of a special nature, are also given.

F. B.

Newcastle-upon-Tyne Electric Tramways.

(Tramway Railway World, vol. xi., January, 1902, pp. 1–12.)

Details of special foundations due to the nature of the ground, and special building work due to the bricklayers' strike are first given. The total length of route is 16½ miles of double track, the maximum gradient 1 in 13½, and the sharpest radius has a curve of 40 feet. The rails are in lengths of 45 feet to 60 feet, and are of steel, having not less than ½ per cent. of carbon. They are 7 inches high and 7 inches wide in the base, and 2 inches broad in the head. The fish-plates weigh 73 lbs. per pair. The rails are laid on a concrete bed extending 18 inches outside the tracks, and are held together by steel tie-bars 2 inches by ⅜ inch. In many places the streets have been re-paved from kerb to kerb, principally with Jarrah wood blocks, but in some places by granite setts 6 inches deep. The whole construction of the road and track is very substantial, and cost £18,000 per double-track mile. The feeder ducts, which are of fire-clay or cement, are laid under the road bed between the tracks. The manholes are 400 feet apart. The rails are bonded with 8-inch flexible bonds, equal in section to 0000 B and S, and are cross-bonded with a wire of the same section at distances of 90 to 135 feet. The poles for the overhead equipment are spaced 120 feet apart, and vary in height from 27 feet 9 inches to 31 feet; and in diameter from 6 inches to 9 inches at the base, and

from 4 inches to $5\frac{1}{2}$ inches at the top. The first equipment of cars includes sixty of the single-deck bogie type with eight wheels, twenty single-deck cars on four-wheeled trucks, and sixty-five double-deck cars on four-wheeled trucks. The wheel base of the single-truck cars is 6 feet, and of the double-truck 15 feet. In the power-house three main generating sets are at present installed, of which the engines are of the vertical inverted type. The largest is a triple-expansion engine of 2,000 I.HP., running at 90 revolutions per minute, with a steam pressure of 165 lbs. per square inch. The other two engines are of 1,000 I.HP., each running at 90 revolutions per minute. The air-pumps for the condensers are worked from the high-pressure cross-head in the case of the large engine, and from the low-pressure one in the case of the smaller sets. Condensing water is obtained from the River Tyne, a $\frac{1}{4}$ mile from the generating station. In a pumping-station on the quay two large centrifugal pumps force the water through a 24-inch pipe to the power station, against a head of 90 feet. After passing through to the condensers, the water falls by gravity through another 24-inch pipe to the pumping station, where it is used to drive two turbines mounted on the same spindles as the pumps. Two electric motors supply the power required, in addition to that developed by the turbines. The large electric generator has twelve poles, and is rated at 1,300 kilowatts, and can give 50 per cent. overload. The two smaller machines are of the ten-pole pattern, each rated at 650 kilowatts. The combined efficiency is 85 per cent. The current is direct at 500–550 volts. Coal is delivered by means of a railway siding, carried on a lofty steel viaduct, into the top of the building directly above the firing floor, where the coal is discharged into overhead bunkers, and is then fed by gravity, through automatic weighers, into the mechanical stokers. Good photographs of the track during construction, of the power station, and of the cars are given; also a sectional elevation of the power station, sections of the rails and bonds, and a plan of the district served by tramway system.

F. B.

The Metropolitan Electric Railway, Paris. DETROYAT.

(Soc. Int. Élect., Bull., vol. ii., pp. 136–155; discussion, February 1902, p. 155.)

The service is one of 550 volts continuous; the current is picked up by cast-iron slides running on an insulated third rail of hard steel, to which the current is brought by cables (bare or insulated) from the feeding centres. The lighting is by series of five 110-volt lamps. Special means are provided by duplicating circuits, etc., to prevent the possibility of panic through total extinction of the light. The generating station at Bercy was described in Abstract No. 1819 (1901), but many additions and modifications have since

been made. The auxiliary dynamos consist of the exciter sets and boosters. The former are rotary transformers, two dynamos on the same shaft connected by an elastic coupling. They are each of about 65 kilowatts capacity, and transform the 600 volts down to 130 volts continuous; they are excited in shunt. The low tension current serves to excite the alternators, and for the works lighting. The boosters, each of 200 kilowatts, transform the generated continuous pressure from 0 to 25 volts, or continuously up to 150 volts, according as the battery is acting as a regulator or is being charged. The motors of the boosters are shunt excited, the generators being compound wound; the series winding is traversed by the full battery current; the shunt winding, connected to the bus-bars on the switchboard, through a rheostat, allows either of balancing the battery according to the pressure of distribution, or of raising the pressure for charging. The converter sets, each of 750 kilowatts, consist of three static monophase transformers, 5,000 to 430 volts, and a rotary converting the alternating current at this latter pressure to direct current at 600 volts. The transformers are delta-connected on the primaries, the secondaries being independent: they are artificially ventilated. The rotaries have six rings on the alternating side, connected to sections on the armature 60° of phase apart. The speed is 250 revolutions per minute. They are started on the direct-current side; efficiency, 88 to 90 per cent. The battery is of 270 elements, and has a capacity of 1,600 ampere-hours at the 1-hour rate: for 24 hours its capacity is trebled, and it can easily debit 3,000 amperes for short periods. *Converter Sub-station.*—The equipment here is similar to the converter equipment at the generating station, and transforms from 5,000 volts alternating to 600 volts direct current. One of the four sets is connected delta-wise on both sides, and runs at 300 revolutions per minute, but no difficulty on this score has been experienced in regard to paralleling. When the line was first operated the Bercy station was not ready, and a temporary supply of current was obtained, first from the Parisian Compressed Air Company (direct current), and later from the Moulineaux and Asnières Companies (5,000 volts, three-phase, 25 periods). Since November 1, 1901, to January 15, 1902, the Bercy station has been in operation, and has been sufficient for the requirements of the line. Since then, however, owing to the increase of traffic, it has been again necessary to call in the assistance of the Moulineaux and Asnières Companies; a new sub-station has been put down at the Louvre, to serve the part of the line between Bercy and the Étoile, and for the line between Bercy and Vincennes a feeder has been installed. *Generators.*—The capacity of the generating station at Bercy is now being increased, a 1,500-kilowatts three-phase generator set being in process of erection, with three new sets of 2,100 kilowatts on order. These are condensing plants, and by means of superheating, etc., it is hoped to obtain a consumption of 5 kilograms of steam per I.HP.-hour. Curves are given of the line current, the highest point touched

being about 2,500 amperes, and also battery charge and discharge curves. On No. 1 line the number of trains running is as follows: 5.30 A.M. to 9 o'clock, 28 trains of from 4 to 7 coaches; 9 to noon, 26 trains of 4 and 5 coaches; noon to 3, 26 trains of 4 to 7 coaches; 3 to 8, 28 trains of 4 to 7 coaches: and 8 to half an hour after midnight, when the service ceases, 12 trains of 4 coaches. The rolling stock, as originally installed, consisted of units of 4 coaches, namely, a locomotive and three trailers. Each locomotive carried two series motors with spur gearing, each of 100 HP., worked by a single series-parallel controller, with magnetic blow out; the usual safety devices, cutouts, fuses, and lightning arresters being provided. The collectors by which the current is picked up are carried by two connecting rods, which permit of a certain freedom of movement both vertically and also sideways for negotiating curves. Owing to the increase of traffic it became necessary to be able at will to increase the size of the trains. This was effected by fitting each locomotive with controllers which will allow either two or four motors to be used at will, so that two of the original units can be worked together. The arrangement, designed by the Thomas-Houston Company, is described. The brakes are worked by compressed air, the compressors being operated by series motors at 550 volts. Tests were made, December, 1900, on a train of three coaches and one locomotive driven by two 100-HP. Westinghouse motors. Starting from rest, with the motors in series, a speed of 6·5 metres per second was attained in 46 seconds, the current in the full-speed position being 150 amperes (at the twentieth second) and then dropping to about 75; the motors being then put in parallel, the current rose to 300 amperes at the fifty-seventh, dropping to 220 at the sixty-third second, by which time the speed had reached 9·5 metres per second. The current being then shut off, the speed decreased uniformly to 6 metres per second at the hundredth second, when the brakes were applied and brought the train to rest in 5 seconds. The curves show that the energy lost in the resistances was 19 per cent. of the total consumption. The specific consumption is 49 watt-hours per tonne-kilometre. A similar test made a year later gave the same result. For lighting and for working the compressors about 3 watt-hours must be added, giving a total of 52 watt-hours per tonne-kilometre. This figure is somewhat high, but is reduced by increasing the tonnage of the trains, which is the present tendency. The total output of the generating station in direct current during December, 1901, was 1,047,568 units, of which 86·1 per cent. was for traction, and the rest for lighting. The total output per train-kilometre was 3,547 units, and 61 watt-hours per tonne-kilometre. Comparing this with the actual consumption per tonne-kilometre, viz., 49 watt-hours, the loss in the line is seen to be over 14 per cent. More recent tests give a loss of about 12 per cent. The signalling arrangements are worked electrically on the automatic block system. Each train as it passes any signal depresses a lever which actuates this signal, leaves the last one at danger, and re-sets the one before

that at "line clear." There is also telephonic communication between all parts of the line. The Paper concludes with a description, accompanied by a map, of the proposed extensions of the line. The estimated power necessary for the working of the line, including these extensions, will be 30,000 kilowatts three phase. During the year 1901 the total number of passengers carried was over 48 millions, or more than 3½ millions per kilometre.

B. P. S.

Hannawa Falls Electric Power System. W. C. Johnson.

(Amer. Soc. Mech. Eng., Trans. 23, No. 919, December, 1901, pp. 131–150.)

The Author describes the hydraulic installation of the Hannawa Falls Water Power Company, which has acquired the land and water rights along the Raquette River, drawing its water from the drainage of the elevated forests of the Adirondack Mountains. The Raquette River drains an area of upwards of 1,100 square miles, and is further remarkable in that it has a drop of about 300 feet in the first 3 miles of its course below Colton, and a further fall of 85 feet in the next 2 miles of its course. The lower 85-feet fall has been developed first. A dam has been built at the village of Hannawa Falls, which forms a pond 2½ miles long, and covering about 200 acres. From this pond the water is conducted by a canal about 2,700 feet long to a forebay, thence by penstocks to the wheels. The tailrace extends about 2,000 feet down from the power-house, being separated from the river by an embankment of earth and stone. The location of the dam, forebay, power-house, and the general plan of the dam and entrance to the canal is shown by illustrations accompanying the Paper, and a general description of the different parts and the materials used for their construction is given by the Author. The dam was completed in 1899, and has had 4·5 feet of water on its crest in two different seasons. The canal from the dam to the forebay, about 2,700 feet in length, is 20 feet in depth from the top of the banks, the bottom being 14 feet below the crest of the dam. The bottom width of the canal is 30 feet, the top width 110 feet, making the inside slopes 2 to 1 in all cases. The section of the canal was made to carry 2,500 cubic feet per second of water, with a velocity of 3 feet per second, it being the intention to use that quantity of water when available. The canal ends in a forebay, in the walls of which there are embedded the ends of seven penstock pipes, six 10 feet, and one 6 feet, in diameter, leading down to the power-house on the bank of the river below. The power-house, which is 250 feet long and 60 feet in width for one-half of the length, and 75 feet for the rest, is two stories high, and has been built between the water of the river and the face of the high bank. The tailraces have been excavated so that the water in them stands 12 feet below the floor when the wheels are running, giving a working head of 84 feet

on the wheels. The building is constructed entirely of Potsdam sandstone and steel. The lower floor of the building, a room 115 feet long and 75 feet in width, is the electric station, containing a 1,250-HP. water-wheel, fed by a 6-foot penstock as mentioned, to either end of which is direct-coupled a 350-kilowatt, three-phase, 4,400-volt generator. Underneath the north end of this room is one of the 10-foot penstocks in which there are three openings for receiving three wheels similar to the one described. To each of two of these wheels will be connected two generators similar to these now connected to the wheel mentioned; the fourth will be provided with an extension shaft, to which will be belted an air compressor and other machinery. The water-wheel consists of two runners of American type on the same shaft, discharging, outward. The water is discharged through quarter turns and draught tubes to the tailrace. The speed is regulated by a Lombard governor geared directly to the gate rigging. The wheel and generators run at 350 revolutions per minute. The two 350-kilowatt generators are of the revolving field type, having 24 poles, and delivering three-phase current at a frequency of 60 periods per second and a pressure of 4,400 volts. The Hannawa Falls Water Power Company owns the electric lighting plant in the village of Potsdam, 4½ miles from the station. A double line has been built, each line consisting of three cables of seven strands, each of No. 10 aluminium wire. This line was figured to transmit 375 kilowatts with a drop of 400 volts, delivering 4,000 volts at Potsdam. The 20,000-volt line is intended to run to the village of Canton, 10½ miles from the station, and thence to the city of Ogdensburg, 19 miles further. For lighting the station and local distribution 220 volts will be used. All of the lower floor of the power-house building not occupied by the electric station, and the whole second floor, will be occupied by a ground wood pulp mill of a capacity of 100 tons per day. The mill has been arranged for the purpose of utilizing the spruce wood available in the region tributary to the Raquette River, and the great pulp wood district of the province of Quebec. The principal industry for which the Hannawa Falls Water Power Company are using the water power is the manufacture of wood pulp. The Author describes fully the different manipulations and machines used in the manufacture, and the necessary precautions taken in order to ensure the regular supply of pulp at the rate of 100 tons per day as stipulated. In the grinder-room are placed two pairs of water-wheels of 3,500 HP. capacity each, on horizontal shafts, supplied with water from two independent 10-foot penstocks, and discharging into a common tailrace. A storehouse is located about 320 feet from the power-house, and piling-ground, sawing, and barking buildings are provided. The entire plant has been designed and built under the personal supervision of the writer of the Paper. The Paper is fully illustrated.

L. G.

Use of 45-foot Rails. T. R. COATES.

(Street Railway Review, vol. xi., November, 1901, pp. 849–851. Paper read before the Roadmasters' and Maintenance of Way Association, Washington, D.C., Oct. 1901.)

Practical use of rails longer than 30 feet has been made on 34 out of 128 American railroads, the lengths varying from 31 feet to 62 feet. The majority of the rails are 33 feet long, and represent a mileage of 14,000 miles. Thirty-three feet has been recommended by the above association and by the American Railway Engineering and Maintenance of Way Association, as a standard. As regards cost, whereas one man can straighten a 30-foot or a 33-foot rail, it takes four men to handle a 60-foot rail, and it is almost impossible to say whether it is straight or not. First cost, therefore, is greater with the 60-foot rail. The cost of maintaining the joints is also greater in the case of the 60-foot rail, owing to expansion and contraction. The 45-foot rail reduces the number of joints by 33 per cent. of the number required for 30-foot rails. If properly laid, special precautions having been taken to provide for expansion, a track with 45-foot rails will ride better than one with 30-foot lengths. The cost of lining and surfacing 45-foot rails is slightly in excess of the cost with 30-foot, although there is a little saving in maintenance.

F. B.

Railway Signalling. I. A. TIMMIS.

(Proceedings of Section I. of the International Engineering Congress, Glasgow, 1902, pp. 22–32.)

The Author deals with modern developments in the practice of railway signalling. Hydraulic systems are failures. Pneumatic systems are operated on either high or low pressure. The Westinghouse system may be taken as a type of the former, the pneumatic pressure being controlled by electrical means. Both are fully described. Of electrical systems, the earliest were worked by primary batteries, which supplied current to small motors. Such, for instance, was the method of the Union Switch and Signal Company of America. A further development introduced the use of secondary batteries. The first automatic electric system of signalling was fitted by the Author on the Liverpool Overhead Railway, the signals being operated by long-pull electro-magnets, actuated by the passing train. At the Paris Exhibition an automatic system was fitted, covering 2 miles of line, similar in general outline to the Liverpool system. The methods of electric

signalling adopted at Crewe are finally described. All the systems above mentioned are explained in detail, and all are further illustrated by drawings. It takes considerably less than a second to lower a signal by electricity or to move and lock a pair of points by electro-magnets. Pneumatic signals at 500 yards distance take 9 or 10 seconds to complete the return current, and it is not practicable to work signals at 1,200 yards except by electrical means.

W. H. S.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1901–1902.—Part III.

N.B.—Titles in italics refer to Original Papers, and those selected for printing only are further distinguished by the suffix "(S.)" or "(St.)," the latter denoting Students' Papers. Abstracted Papers are not so indicated.

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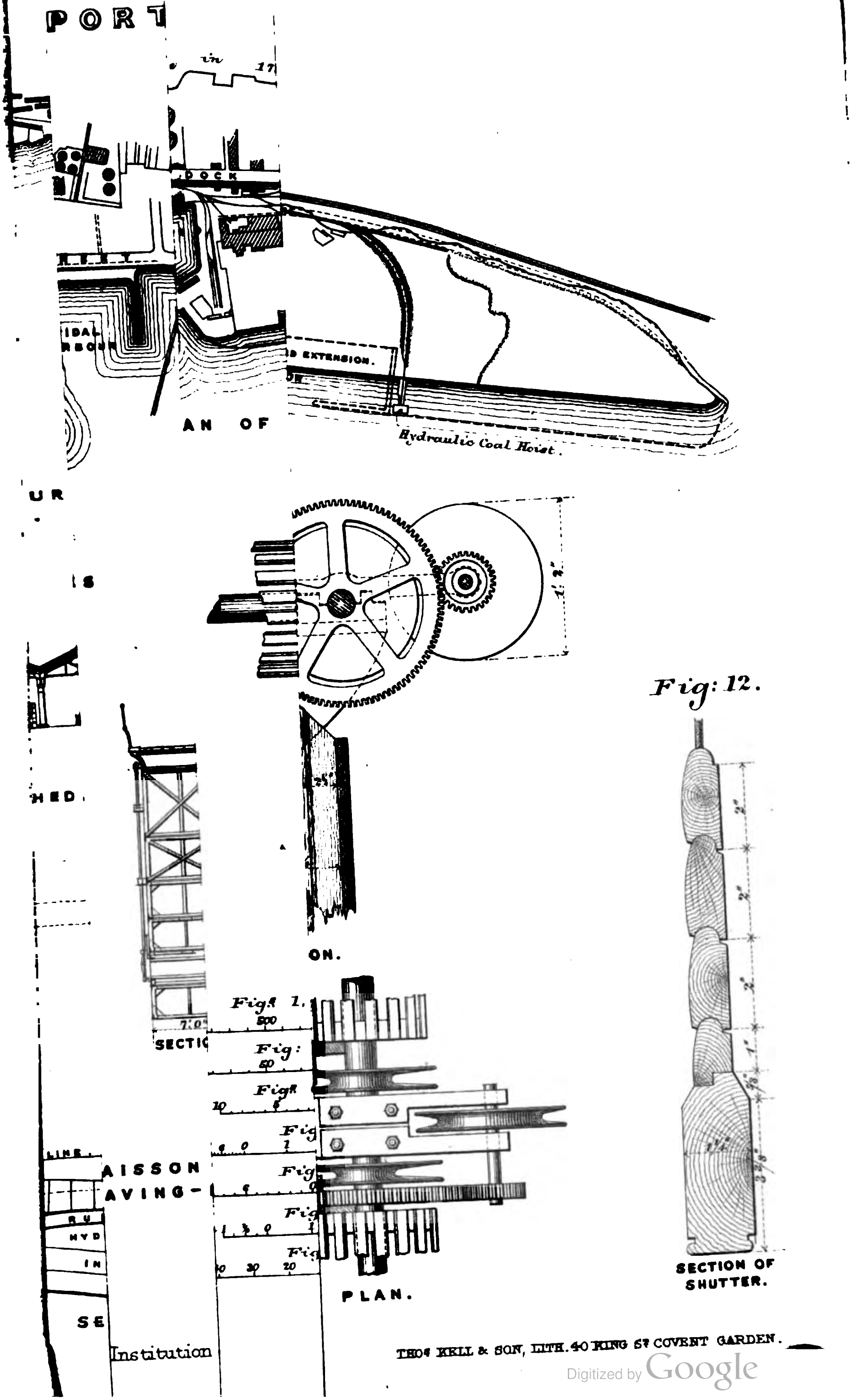
PLATE 1.



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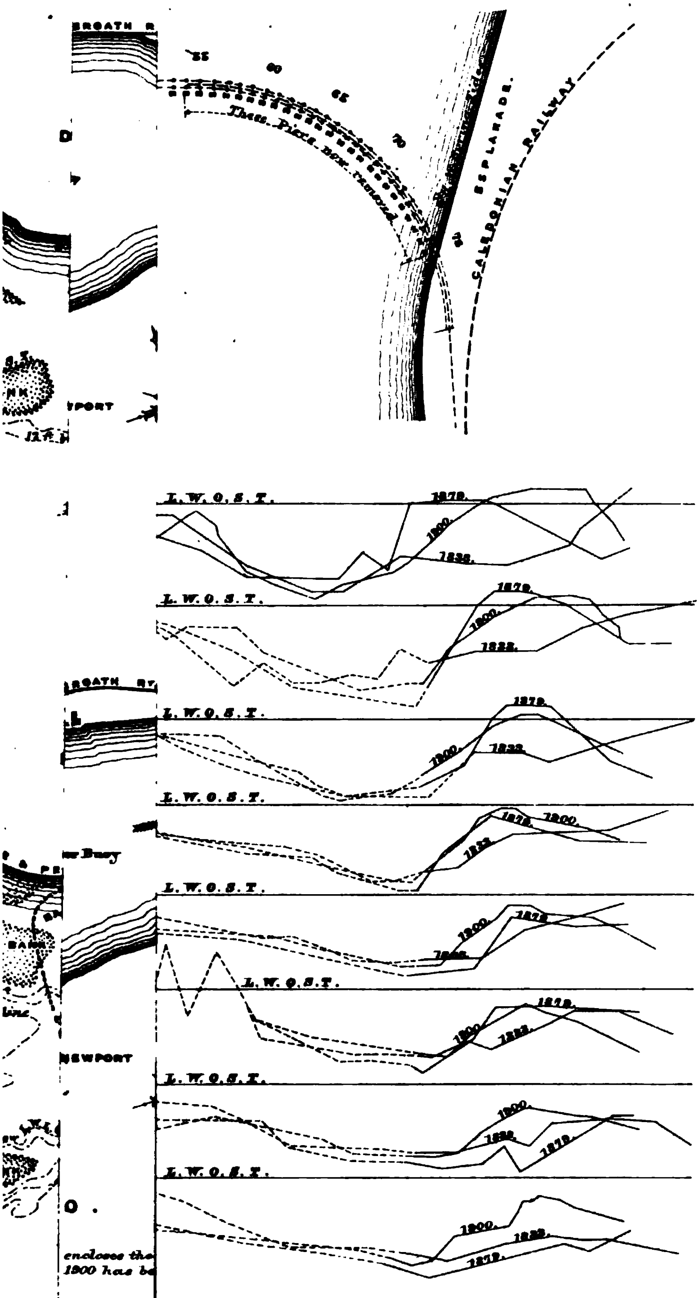

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THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

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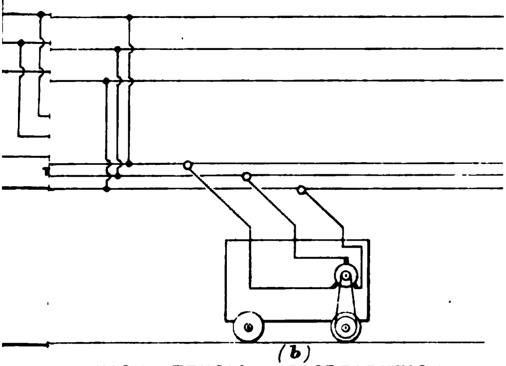
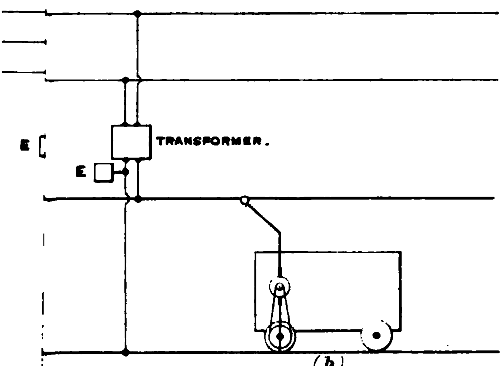
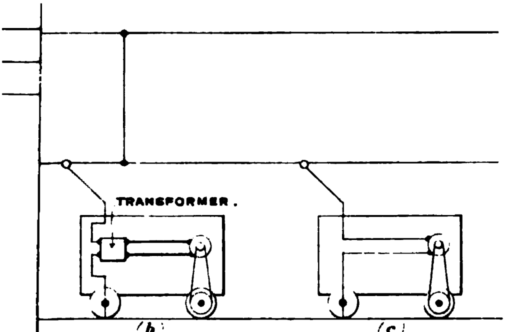
PLATE 3.



. HIGH-TENSION DISTRIBUTION.
STAT REE CONDUCTORS.
) HIGH-TENSION MOTOR.



ASE P-DOWN TRANSFORMER AT SUB-STATION.
CTOR; RAIL RETURN.
RY R. (b) SINGLE-PHASE MOTOR.

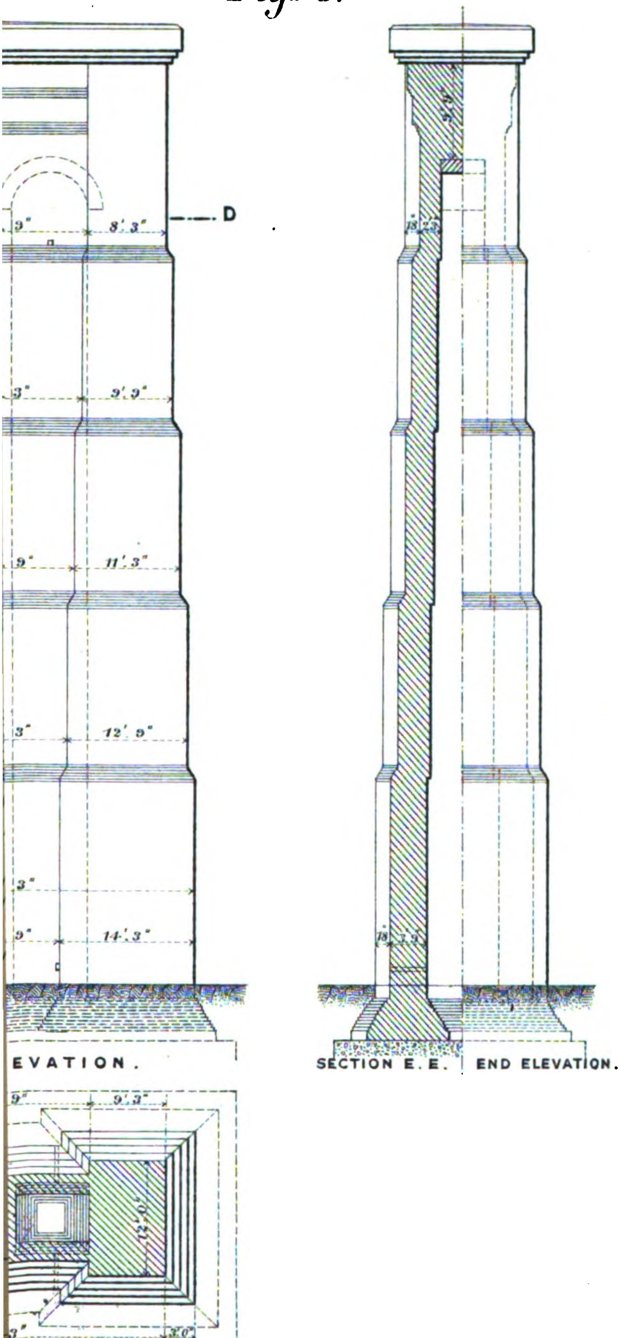


HIGH-TENSION DISTRIBUTION.
AS CTOR; RAIL RETURN.
JB ER AND SINGLE-PHASE MOTOR. (c) SINGLE PHASE HIGH-TENSION MOTOR.

X. THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN

PLATE 4.

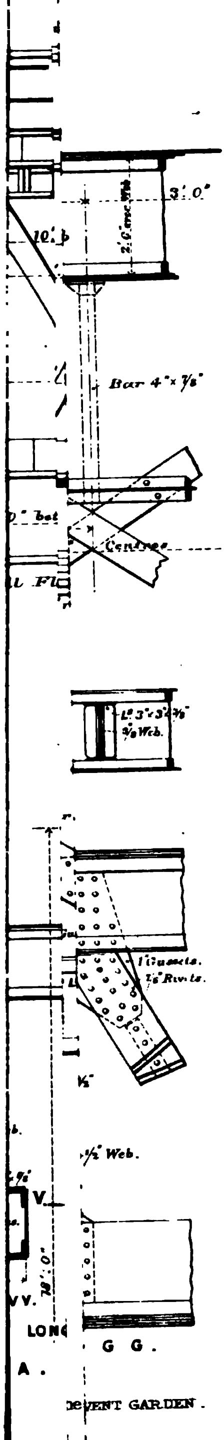
Figs. 3.



EVATION. SECTION E. E. END ELEVATION.

PLAN D. D.

PLATE 5.


3' 0"
2' 6" over Web
Bar 4" x 7/8"
Centres
L^s 3" x 3" x 3/8"
3/8 Web.
Gussets.
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V.
V.
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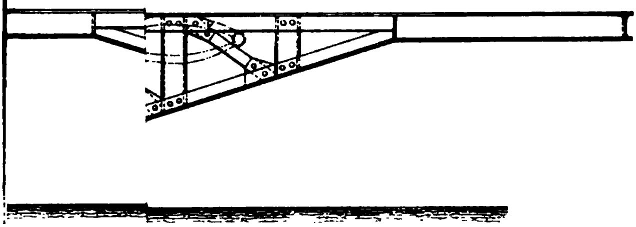
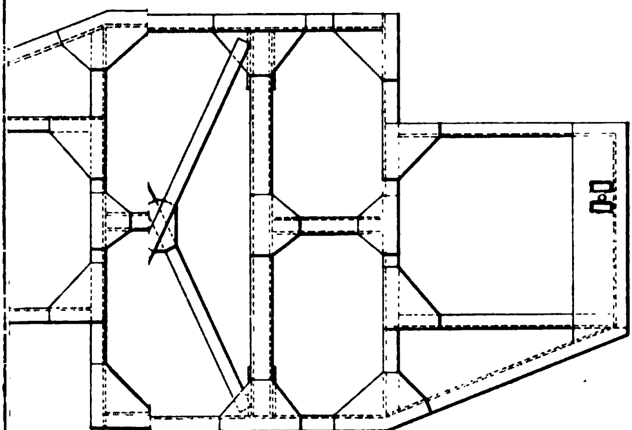
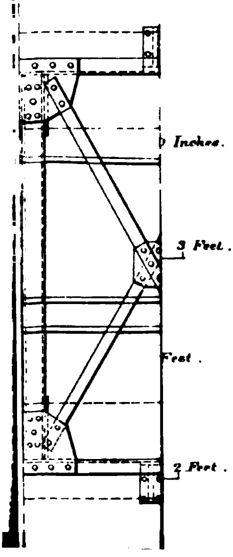
G G.
A.
COVENT GARDEN.







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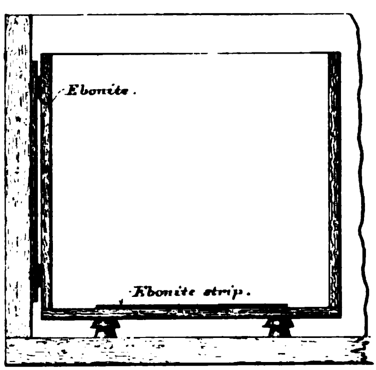

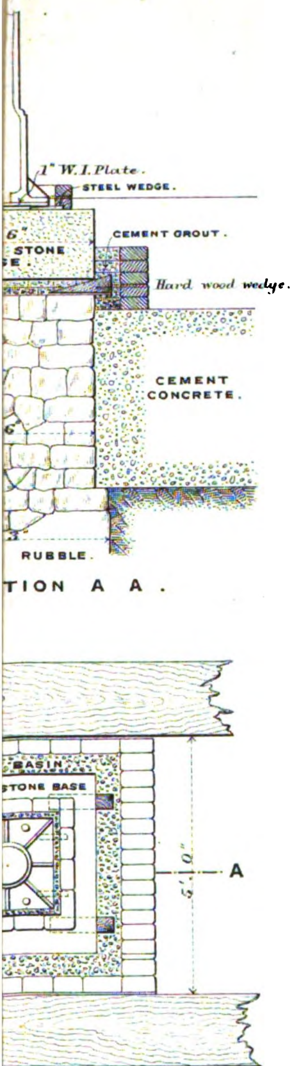

TION A A.

AN.

THOS KELL & SON, LITH. LONDON